Chapter 14
Impacts of Climate Change on Precipitation Climatology and Variability in Turkey

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Abstract In this chapter, changes in seasonal precipitation climatology, extreme weather conditions, and aridity conditions of Turkey are evaluated for the period of 2021–2050 with respect to the reference period of 1971–2000 by using regional climate model simulations. Projections of future climate conditions are modeled by forcing Regional Climate Model, RegCM4.4 of the International Centre for Theoretical Physics (ICTP) with MPI-ESM-MR global climate model of the Max Planck Institute for Meteorology. The outputs of MPI-ESM-MR are used to generate 10 km resolution data by the double nesting method under both RCP4.5 and RCP8.5 emission scenarios. The seasonal time-scale performance of RegCM4.4 in reproducing the observed climatology over Turkey is tested by using the output of the global climate model. The projection results show a strong decrease in precipitation for almost all parts of the domain according to the output of the regional model. The intensity of drought conditions is projected to increase. According to the projection results, more arid conditions are expected in the region for the near future. Therefore, drier than present climate conditions are projected to occur more intensely over Turkey.

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14.1 Introduction

Water resources are gradually shrinking due to the decrease in precipitation and the increase in evapotranspiration that stem from increasing global temperatures. These dry conditions will limit the sustainability of regional water resources in the near, mid, and long term. Therefore, in this section, precipitation climatology in Turkey is analyzed in order to see especially the potential impact of climate change on total precipitation amounts, aridity conditions, and precipitation extremes.

For the future period of 2070–2099 with respect to 1960–1989, temperature increases and precipitation declines are predicted in the Mediterranean Region (Gibelin and Déqué 2003). The decrease in average precipitation is associated with a significant decrease in soil moisture and is expected to have an impact on water resources in the Mediterranean Basin (Gibelin and Déqué 2003). It has been observed that the cyclones throughout the Mediterranean region affect the climate and the weather conditions of the region. The cyclones cause changes in fundamental climate parameters such as temperature and precipitation, and extreme weather events such as storms and floods. Extreme weather events are unpredictable because the reasons causing these events are very diverse (Lionello et al. 2006a). Observations of precipitation between October and March in the Mediterranean indicate that precipitation has increased from the mid-nineteenth century to the mid-twentieth century and reached its maximum levels in the 1960s. It started decreasing from that date forward and declining rapidly towards the end of the twentieth century (Xoplaki et al. 2004). In the winter months, there is a positive trend of average precipitation in the northern Mediterranean, while a negative trend is observed in the southern part. In other seasons, a decrease is broadly foreseen, especially in the summer. However, in the case of extreme precipitation and arid periods, not only temporal shifts occur, but also the probability and frequency of their occurrence increase, leading to the possibility of floods and droughts (Gao et al. 2006). In the Mediterranean region, a decrease in winter precipitation and a temperature increase of 0.75 °C has been observed especially in the last century. In the same region, temperature increases of 4–7 °C and changes in the order of −40% to +20% in precipitation are expected in the next century (Lionello et al. 2006b). Annual maximum and minimum temperatures have been observed for the summer and winter seasons in the future periods of 2030–2059 and 2070–2099 with respect to the reference period of 1979–1999. The greatest increase in maximum temperature is seen in southern Europe. Average precipitation is decreasing in the Mediterranean Basin and southern Europe in winter, spring and summer seasons. In addition, an increase is observed in the precipitation extremes in autumn, winter and spring seasons throughout the region (Goubanova and Li 2007).

Except for the Northern Mediterranean (such as the Alps), there is a significant decrease in precipitation, and the highest increase in temperature occurs during the summer months. This increase between the years, especially in summer, also causes extremely high temperature events in summer (Giorgi and Lionello 2008). Another study examining the precipitation trends in the Mediterranean region between 1951 and 2000 indicates a significant decrease during the winter season between October and March. Besides, there is an increase in precipitation in the northern and western Mediterranean during the winter, and a decrease in precipitation in the spring and autumn. However, negative changes in all precipitation periods are noteworthy in the Southern and Eastern Mediterranean regions (Jacobeit et al. 2007). When the future precipitation regime for the winter is examined by dividing the Mediterranean Region into north and south, an increase in precipitation in the northern parts of the Mediterranean Basin and a decrease in precipitation in the southern part are anticipated. These results indicate that climate change is not distributed homogeneously in the Mediterranean (Lionello and Giorgi 2007). Average annual temperature increases in Europe are projected to be higher than the world average, and it is expected that the maximum seasonal warming will be in northern Europe in winter and in the Mediterranean region in summer. It is very likely that the majority of the Mediterranean will have a decrease in precipitation and wet days. Most probably, the precipitation and evaporation trends in the Mediterranean Region indicate that hydrological droughts will increase especially in the summer months. Besides, it is highly likely that there will be a decline in the number of snowy days and snowfall in Europe in general (Calbó 2009).

Under the A2 SRES scenario in the years 2071–2100 compared to the 1971–2000 period, a precipitation decrease of 1.75 mm/day in the winter in the southern part of Turkey is expected. Similar decreases are also foreseen for spring and summer seasons as well. The B1 SRES scenario, which is the optimistic case like RCP4.5, also has trends similar to the A2 scenario, which is the pessimistic case like RCP8.5, but it is predicted that these trends will be less severe (Altinsoy et al. 2011).

In particular, a significant increase in the minimum nightly temperatures in Turkey, especially in the Mediterranean Basin in the spring and summer seasons, are observed. When the period 1901–2005 is examined, it can be seen that the amount of precipitation increased by 1% in the top half of the northern hemisphere, while it decreased by 3% in the Mediterranean Basin in 10 years. In general, it has been determined that there is a remarkable decrease in the number of frosty and snowy days, especially after 1990s, and an increase in the number of warm days and nights, with the lowest nighttime and the highest daytime temperatures in the Eastern Mediterranean. Long-term declining trends in precipitation since 1970s and arid conditions have been particularly influential in most of the Mediterranean region. Turkey is one of the regions most affected by this drought. In the future projection of 2071–2100, an increase in precipitation is expected at 0.5–2 mm/day in the whole Mediterranean Basin in winter months and an increase between 2.5 and 5 °C in winter temperatures. A rise in summer temperatures of 1 °C is expected and further increase is predicted in the spring and autumn seasons (Turkes 2012a).

Between 1960 and 2010, it is observed that the precipitation trends decline in the Mediterranean Region. It is more likely to happen in maximum daily precipitation. According to the RCP4.5 and RCP8.5 scenarios, it is predicted that precipitation decreases in all seasons in the eastern Mediterranean region (Akcakaya et al. 2013). In the Mediterranean Region, based on the years 1970–2000 for the future period of 2070–2100, the increases in temperature are the highest in summer and the lowest in winter. Besides, a decrease in precipitation is foreseen in almost all seasons in the whole Mediterranean (Ozturk et al. 2015). According to the RCP4.5 scenario, precipitation decreases by 20% between 2041 and 2070 for the eastern Mediterranean, and depending on the RCP8.5 scenario, increases in the western Mediterranean during the rainy season and decreases in the eastern Mediterranean between 2016 and 2040. Reductions in precipitation in the Mediterranean are predicted between 2041–2070 and 2071–2099 during the summer (Demircan et al. 2017). Between the years 1979 and 2011, especially one of the most important causes of extreme precipitation in the south of Turkey is the upper air turbulence moving west to east and strong low pressure systems over the eastern Mediterranean basin. Extreme rainfall variability during the year occurs more frequently at the end of autumn and the beginning of winter. Extreme events usually last for 1 day, and there are no extreme weather events lasting 4 days (Lolis and Turkes 2017).

When precipitation periods in Turkey are analyzed, maximum precipitation is seen in December–January, while minimum precipitation is observed in July–August (Kadioglu et al. 1999). Considering the long-term annual average and monthly total precipitation in Turkey, a downward trend in precipitation is observed overall Turkey. Between 1° and 6 °C temperature rise and decline in precipitation except for winter months is expected in the 2016–2099 future period. A decrease in precipitation in autumn throughout Turkey is expected except for some local regions (Demircan et al. 2017). An increase in temperature between 5° and 7 °C for the summer in almost all of Turkey and a decrease of 40% in precipitation across the southern and western sections in the future period of 2071–2100 are predicted. Due to rising temperatures and decreasing precipitation, drought events are expected to increase in severity, frequency and duration. However, it is anticipated that, in the hot seasons, the amount of water in the rivers that are fed with melted snow will experience a decrease as a result of the increased temperature. Also, it is expected that the agriculture sector will be affected due to the decrease in water amount and increase in the number of arid days due to increasing temperature and decreasing precipitation (Sen et al. 2012; Sen 2013).

According to the past data of 1860–2005 and the 2005–2100 RCP4.5 scenario, the Mediterranean Region has been found to be warm and arid. Studies conducted with future projections have also shown that the drought and warming in the Mediterranean region will take place at a greater rate than in the past until the end of the twenty-first century (Mariotti et al. 2015). Furthermore, from the mid-twentieth century, the increase in average temperature in the entire Mediterranean Basin is greater than the increase in the global mean temperature, and a decrease in annual mean precipitation is observed. Since the 1960s, the intensity, duration, and number of heatwaves on the eastern Mediterranean have increased at least five times

(Ruti et al. 2016). Moreover, aerosols and greenhouse gases change the water cycle and affect the drought of the Mediterranean by affecting the cloud properties and the radiative balance in the Basin. Accordingly, from the early twentieth century, the precipitation in the Mediterranean tends to decrease (Tang et al. 2018). Gediz Basin, located in the western Mediterranean, is examined for the future period of 2017–2099, related with the 1985–2005 scenario; accordingly an increase of 0.8 °C of the annual mean temperature under RCP4.5 (optimistic scenario) and 2.0 °C under RCP8.5 (pessimistic scenario), and also a decrease of 35 mm/year of precipitation under RCP4.5 and a decrease of 90 mm/year under RCP8.5 are observed (Gorguner et al. 2017).

14.2 Data and Model Description

Regional climate model, RegCM, has been effectively used as a dynamical downscaling tool and applied to several domains (i.e. the Mediterranean, Africa, North America, Central America, South America, East Asia, Central Asia, South Asia, Europe) for regional climate change and climate variability studies over the last two decades (Almazroui 2012, 2016; Almazroui et al. 2016; Chen et al. 2003; Coppola et al. 2014; Gao et al. 2002; Giorgi et al. 2004a, b, 2012, 2014; Gu et al. 2012; Ozturk et al. 2011, 2012, 2017, 2018; Mariotti et al. 2014; Turp et al. 2014; Sylla et al. 2016). For purposes of this chapter, the regional climate change simulations are conducted using the version 4.4 of RegCM, which is a hydrostatic regional climate model developed by the Abdus Salam International Centre for Theoretical Physics (ICTP) (Giorgi et al. 2012; Pal et al. 2007). The dynamic structure of RegCM4.4 is the hydrostatic version of the Pennsylvania State University's National Atmospheric Research Center (National Center for Atmospheric Research (NCAR) of the Pennsylvania State University), which is called MM5 (the Mesoscale model) (Grell et al. 1994). SUBBATS (Giorgi et al. 2003a, b), which is the sub-grid scaled version of the previous scheme of BATS1E (Biosphere-Atmosphere Transfer Scheme) (Dickinson et al. 1993), is used for the surface. Community Land Model (CLM) version 3.5 is also included in the dynamic structure of the code as an option (Oleson et al. 2008; Tawfik and Steiner 2011). Radiative transfer in RegCM4.4 is modeled by using NCAR Community Climate Model, version CCM3 radiation package (Kiehl et al. 1996). It is modeled through the solar radiation transfer δ-Eddington approach (Kiehl et al. 1996). The part of the cloud radiation uses three parameters including the amount of cloudiness, cloud liquid water content, and effective droplet radius. In the model, planetary boundary layer PBL scheme, based on the non-local diffusion concept developed by Holtslag et al. (1990), is used. Convective rainfall patterns of the model are calculated by choosing one of the three schemes, namely the modified-Kuo scheme (Anthes 1977; Anthes et al. 1987), Grell scheme (Grell 1993), and the MIT-Emanuel scheme (Emanuel 1991; Emanuel and Živkovic-Rothman 1999). In this chapter, BATS (Biosphere and Atmosphere Transfer Scheme) (Dickinson et al. 1993) is used as the land-surface scheme, and Grell scheme is used as a cumulus convection scheme with the Fritsch-Chappell type closure (Fritsch and Chappell 1980).

Projected changes in mean precipitation climatology, precipitation extremes and aridity conditions during the period of 2021–2050 (near-term) with respect to the reference period of 1971–2000 are investigated for Turkey, using regional climate model simulations. The outputs of MPI-ESM-MR (global circulation model of the Max Planck Institute for Meteorology) (Taylor et al. 2012) are dynamically downscaled to 10 km resolution by using the double nesting method under both RCP4.5 and RCP8.5 emission scenarios (Van Vuuren et al. 2011). RCP4.5, which is a medium-low emission scenario, stabilizes after 2100 at 4.5 $W{\cdot}m^{-2}$ without overshoot pathway, while RCP8.5 is the highest of the four reaches at 8.5 $W{\cdot}m^{-2}$ in 2100 on a rising trajectory.

14.3 Projected Changes in Precipitation Climatology

14.3.1 Model Biases in Seasonal Temperature and Precipitation Climatology

In this chapter, the regional climate model's performance is first investigated for simulation of the observed climate of the region by comparing model results with the CRU observational dataset. The Climatic Research Unit (CRU) dataset of the University of East Anglia comprises a 0.5° grid resolution monthly mean climatology of multiple variables for global land surface, excluding Antarctica (Mitchell and Jones 2005). Model's skill in simulating observed climatology is spatially evaluated for seasonal temperature and precipitation values. For this purpose, the regional climate model is run with the forcing data of MPI-ESM-MR global climate model for the period of 1971–2000 to investigate model biases for four seasons, which are taken as December-January-February (DJF, winter), March-April-May (MAM, spring), June-July-August (JJA, summer), and September-October-November (SON, autumn).

Seasonal temperature values obtained from the RegCM4.4 driven by MPI-ESM-MR global datasets are presented in Fig. 14.1. The seasonal surface temperature values of observational gridded CRU dataset are also represented in Fig. 14.2 for comparison. The outputs obtained from the regional climate model show detailed temperature distribution with respect to the CRU data due to higher resolution (10 km). Results of the regional climate model show that the climatology of the Turkey domain is reproduced for all seasons. Outputs of the regional climate model produce colder temperature values than the results of the observational dataset, especially during the winter season around mountainous and higher plateaus terrains of the domain, like the south-east part of Turkey. This bias could be due to bias in measurements at the stations because the climatological and meteorological stations are very likely constructed in the valleys of the mountainous parts of the region. In

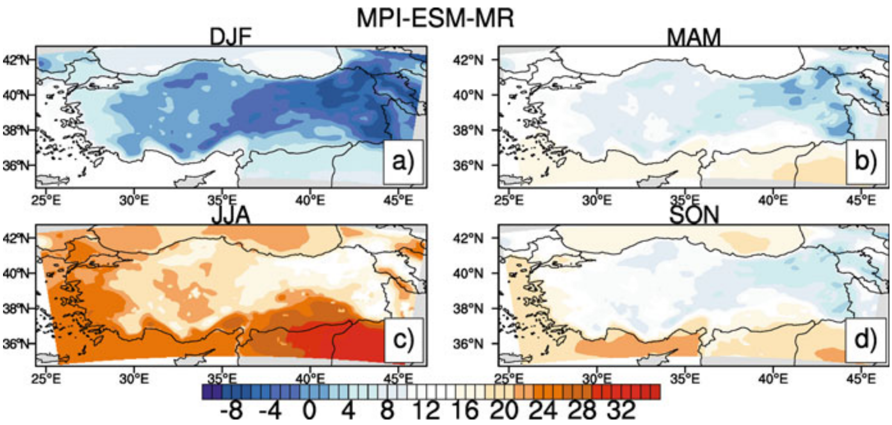

Fig. 14.1 Mean air temperatures (°C) obtained from RegCM4.4 with MPI-ESM-MR dataset for the period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

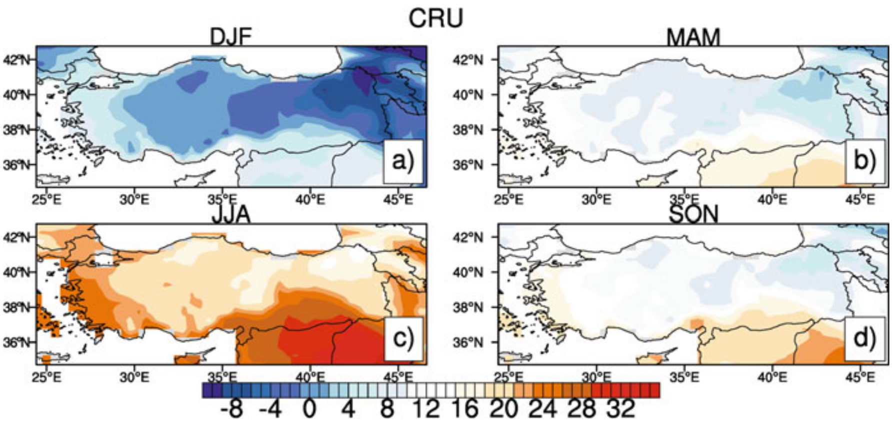

Fig. 14.2 Mean air temperatures (°C) obtained from CRU dataset for the period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

other parts of the domain, the regional climate model produces similar results with the observational dataset.

Seasonal precipitation values obtained from the RegCM4.4, driven by MPI-ESM-MR global datasets and the observational gridded CRU dataset, are represented in Figs. 14.3 and 14.4, respectively. Results show that the regional climate model overestimates precipitation over almost all part of the domain, especially for colder seasons when Turkey has wet conditions. The reason for this bias in estimation can be the fact that RegCM overestimates air pressure and water vapor values along with lower wind speeds compared to the driving datasets (Almazroui et al. 2015). Model outputs agree with observations for the summer season. Therefore, the overall performance of the regional climate model, RegCM, is reasonable.

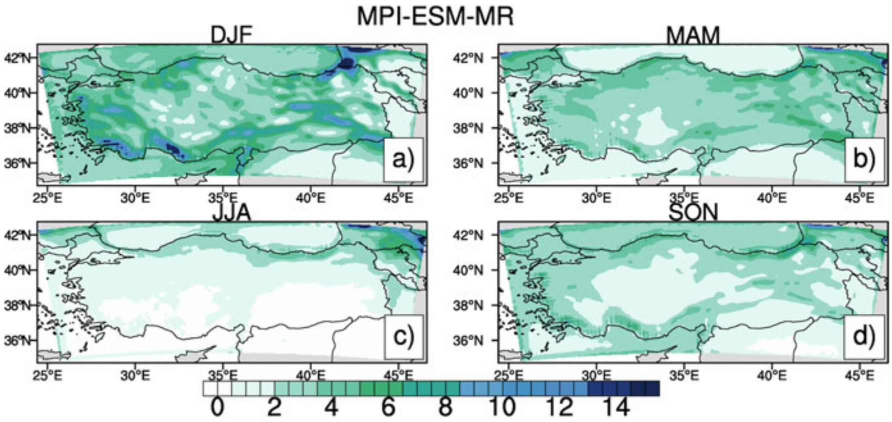

Fig. 14.3 Average precipitation amounts (mm/day) obtained from RegCM4.4 with MPI-ESM-MR dataset for the period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

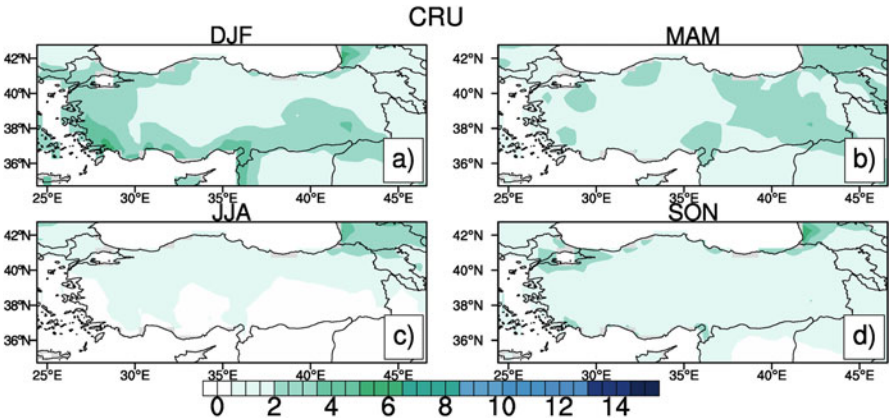

Fig. 14.4 Average precipitation amounts (mm/day) obtained from CRU dataset for the period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

14.3.2 Changes in Precipitation Climatology

The projected changes in precipitation for the future period of 2021–2050 with respect to the present period of 1971–2000, based on the IPCC's RCP4.5 and RCP8.5 emission scenarios, are presented in Figs. 14.5 and 14.6. According to the model results, there is no marked change in the amount of precipitation in the all parts of the domain for dry seasons, which are summer and autumn. Results show much decrease in precipitation amounts with respect to the present period, especially over the south-west part of Turkey for the winter season. On the other hand, there will be an increase in precipitation over the northern part of Turkey.

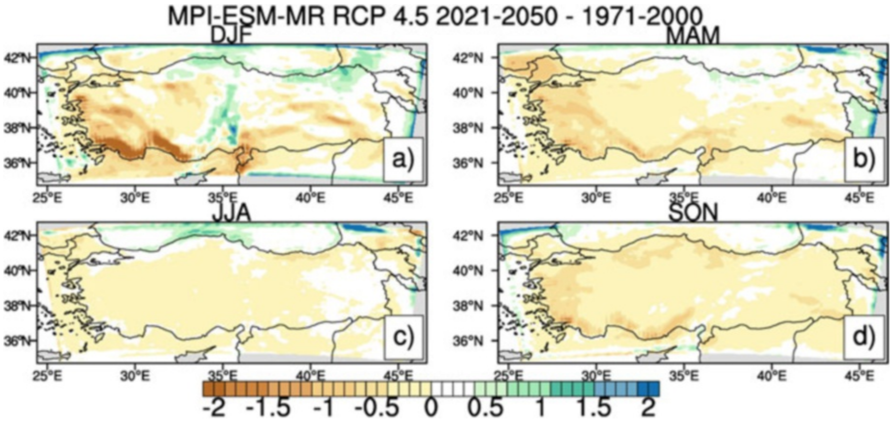

Fig. 14.5 Projected changes in precipitation (mm/day) using the Regional Climate Model RegCM, which is forced by the Global Climate Model MPI-ESM-MR with RCP4.5 emission scenario for the period of 2021–2050, with respect to the reference period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

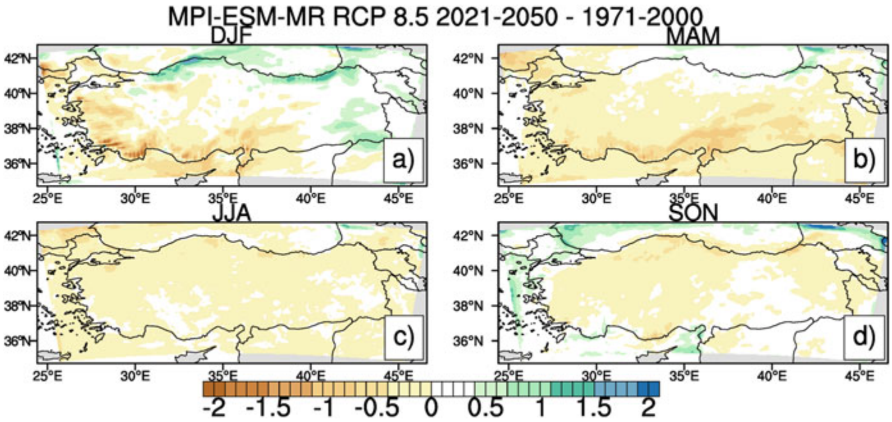

Fig. 14.6 Projected changes in precipitation (mm/day) using the Regional Climate Model RegCM, which is forced by the Global Climate Model MPI-ESM-MR with RCP8.5 emission scenario for the period of 2021–2050, with respect to the reference period of 1971–2000: (**a**) Winter, (**b**) Spring, (**c**) Summer, and (**d**) Autumn season

The regional climate model simulates drier conditions for most part of Turkey, which is already arid and semi-arid. Model outputs of both RCP4.5 and RCP8.5 emission scenarios show alike results for future projections of precipitation. According to the atlas of global and regional climate projections of the IPCC Fifth Assessment Report (AR5), most parts of the South Europe/Mediterranean domain experience a decrease in average precipitation (IPCC 2013). Decrease in precipitation will be significant over the southern-southwestern parts of Turkey and Cyprus in the winter season for the period of 2081–2100, with respect to the period of 1986–

2005 (IPCC 2013). The regional climate model, RegCM, gives more or less similar results with the mentioned in AR5 over Turkey even for the near future.

14.4 Evaluation of Precipitation Extremes

In order to evaluate the change in precipitation extremes, 9 different climate indices are used. These climate indices, except the daily maximum precipitation amount, are chosen among the core indices defined by the CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) (Karl et al. 1999; Peterson et al. 2001; Zhang et al. 2005). Firstly, all of the indices are computed using the daily precipitation output of RegCM for both the reference period (1971–2000) and the near-future period (2021–2050). Subsequently, annual and/or seasonal changes in multi-year averages are illustrated.

The definitions of the 9 climate indices for precipitation extremes are as follows:

Consecutive dry days index: number of the dry periods where the daily precipitation amount is less than 1 mm for at least consecutive 5 days

Consecutive wet days index: number of the wet periods where the daily precipitation amount is more than 1 mm for at least consecutive 5 days

Wet days: number of days where the daily precipitation amount is at least 1 mm

Heavy_10_mm: number of days where the daily precipitation amount is at least 10 mm

Heavy_20_mm: number of days where the daily precipitation amount is at least 20 mm

Heavy_25_mm: number of days where the daily precipitation amount is at least 25 mm

Maximum precipitation: daily maximum precipitation amount

Wet days with respect to the 90th percentile of the reference period: the percentage of wet days where the daily precipitation amount for the future period is greater than the 90th percentile of the daily precipitation amount for the reference period

Wet days with respect to the 95th percentile of the reference period: the percentage of wet days where the daily precipitation amount for the future period is greater than the 95th percentile of the daily precipitation amount for the reference period.

When the change in the number of wet days is examined (Fig. 14.7), it is expected that the decreases in the western and southern regions of the country will reach an average of 20 days in the near future according to the RCP4.5 scenario. Also increases by at least 10 days in the Black Sea coastline are expected. According to the RCP8.5 scenario, a reduction in the number of wet days is foreseen over almost all the country. It is expected that this decline will be more around the Middle Taurus Mountains.

When the changes in daily extreme precipitation are analyzed under both scenarios, it is projected that the number of heavy (daily precipitation amount $\geq$ 10 mm) and very heavy (daily precipitation amount $\geq$ 20 mm and 25 mm) precipitation days

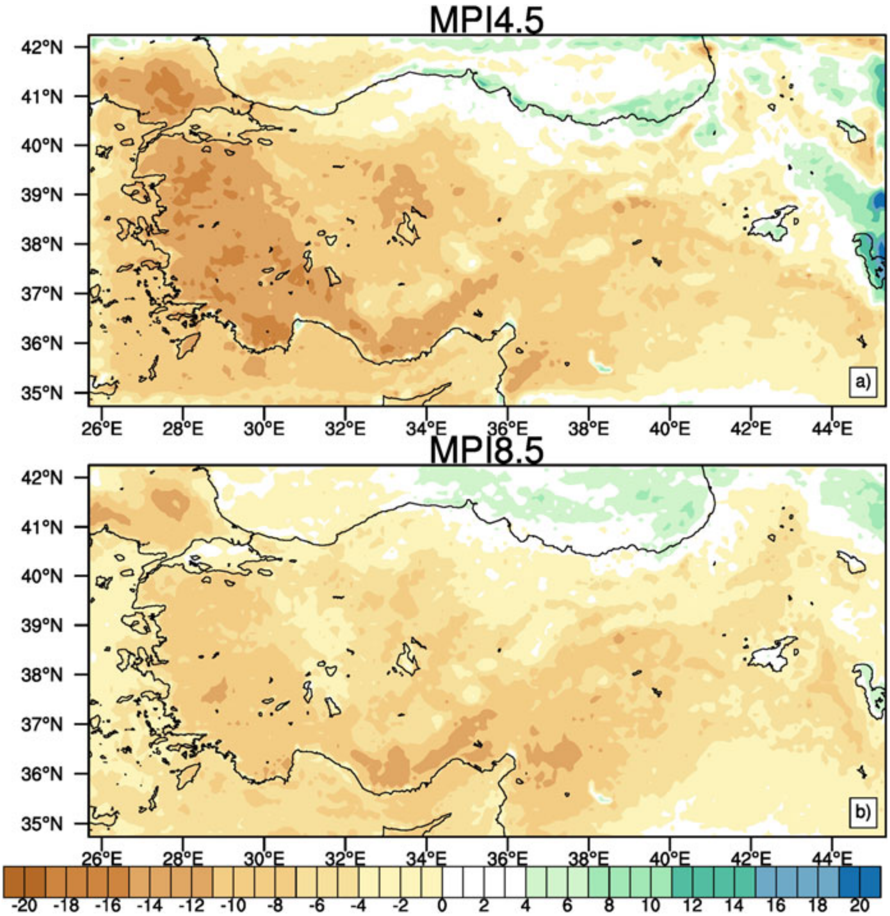

Fig. 14.7 Annual average changes in wet days under (**a**) RCP4.5 scenario and (**b**) RCP8.5 scenario for the period of 2021–2050 with respect to the reference period of 1971–2000

in the future will decrease except at the Black Sea coasts (Fig. 14.8). This reduction is expected to be greater in the RCP4.5 scenario. The number of days when the daily total precipitation amount is greater than or equal to 10 mm, especially in the southern and western Turkey, will decrease more than that in other areas, while it will increase in the Black Sea region. A similar change is anticipated in the number of days when the total daily precipitation amount is greater than or equal to 20 mm and 25 mm, but this change is to be less than that seen on 10 mm and above wet days.

According to the RCP4.5 scenario, consecutive dry days in the future will increase in the west of the country, while in other regions, it is expected to show a slight decrease in general (Fig. 14.9a). According to the RCP8.5 scenario, an increase towards southern Marmara and the southwestern and inner Anatolian regions; a fair amount of decrease in other places are assumed (Fig. 14.9b). When

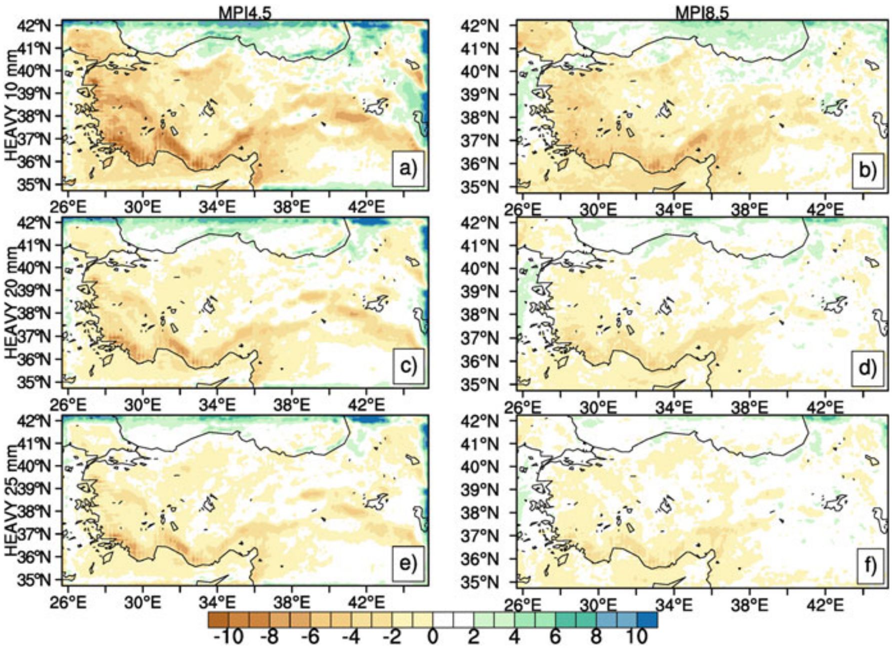

Fig. 14.8 Projected changes in the number of heavy and very heavy precipitation days for the period of 2021–2050 with respect to the reference period of 1971–2000. Change in (**a**) 10 mm wet days, (**c**) 20 mm wet days, (**e**) 25 mm wet days under RCP4.5 scenario, (**b**) 10 mm wet days, (**d**) 20 mm wet days, (**f**) 25 mm wet days under RCP8.5 scenario

consecutive wet days are examined, the opposite view of consecutive dry days is encountered (Fig. 14.9). The consecutive wet days under the RCP4.5 scenario will decrease in the west of the country and increase in the middle and eastern Black Sea, as well as in northeastern parts of the country (Fig.14.9c). On the contrary, under the RCP8.5 scenario, a decrease in the consecutive wet days will be expected in the whole country, which will be more especially over the Antalya-Karaman-Mersin region (Fig. 14.9d). According to the RCP8.5 scenario, the increase in the vicinity of Sinop and Kastamonu provinces contrasts with the change seen throughout the country.

It is predicted that the annual maximum daily precipitation amounts will decrease by 5 mm/day in the entire country according to the RCP4.5 scenario (Fig. 14.10a). This decline is expected to be greater across the Thrace, coastal Aegean and Mediterranean regions. According to the RCP8.5 scenario, the average daily maximum precipitation is expected to increase slightly along the Black Sea coastline, while a decrease of up to 2 mm/day is expected in the country (Fig. 14.10b). It is predicted that the amount expected to be realized according to the RCP4.5 scenario will be relatively higher than the RCP8.5 scenario.

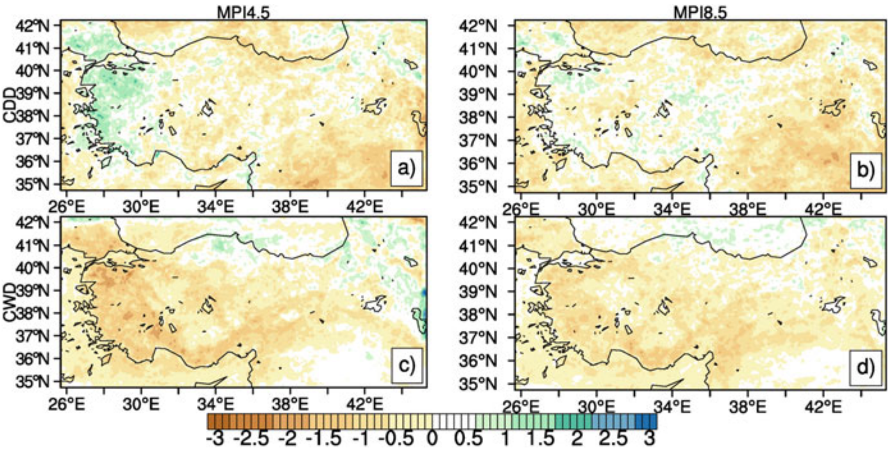

Fig. 14.9 Projected annual average changes in consecutive dry days for the period of 2021–2050 with respect to the reference period of 1971–2000: (**a**) RCP4.5 scenario, (**b**) RCP8.5 scenario; and annual average change in consecutive wet days for the period of 2021–2050 with respect to the reference period: (**c**) RCP4.5 scenario, (**d**) RCP8.5 scenario

Figure 14.11 shows the annual average percentage of days when the daily precipitation amount in the near-future is above the 90th percentile of the reference period. Under the RCP4.5 scenario, 5% of the winter season (about 5 days) in Turkey will have heavier precipitation conditions than those happened in the past. This percentage rate will reach 20% (18 days) in the summer season. RCP8.5 scenario-based projection gives similar results with the RCP4.5 scenario-based projection results for the winter season, while it projects more days with heavy precipitation (25% – around 23 days) than those seen in the RCP4.5 scenario.

Figure 14.12 shows the seasonal average percentage of days when the daily precipitation amount in the near-future is above the 95th percentile of the reference period. Under the RCP4.5 scenario, 5% of the winter season (about 5 days) in Turkey will have heavier precipitation conditions than those happened in the past. This percentage rate will reach 10% (9 days) in the summer season. RCP8.5 scenario-based projection gives similar results with the RCP4.5 scenario-based projection results for the winter season, while it projects more days with heavy precipitation (15% – around 13 days) than those seen in the RCP4.5 scenario.

14.5 Evaluation of Aridity Conditions

Increase in aridity conditions with climate change and/or land degradation depending on human activities is a very crucial global issue in terms of future risks due to food security and health conditions. Decreases in total precipitation

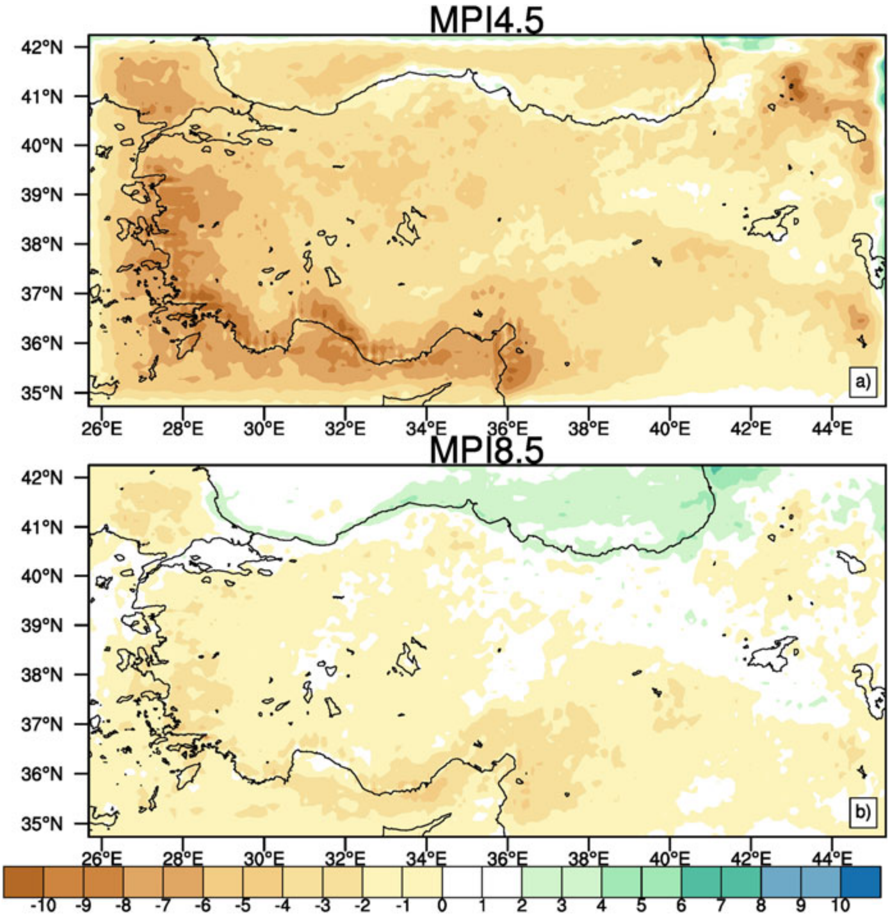

Fig. 14.10 Projected annual changes in daily maximum precipitation (mm/day) for the period of 2021–2050 with respect to the reference period of 1971–2000 under (a) RCP4.5 scenario, (b) RCP8.5 scenario

over the years, repeated dry seasons, and increasing severity and duration of drought events accelerate the transition to desertification (Turkes 2012b, c).

Aridity can be described briefly as climatological drought (Turkes 1998, 2012b, c). The areas where the climatologically long-term dry conditions (i.e. climatological drought) is seen throughout the year are called arid or arid areas (Turkes 2012a).

Aridity Index (AI) can be considered as a bioclimatic index since it takes into account both the physical (precipitation and evaporation) and the biological processes (plant transpiration). Moreover, this index is one of the most suitable indicators to examine the processes of desertification (Middleton and Thomas 1997; Arora 2002; Salvati et al. 2009; Turkes 2013).

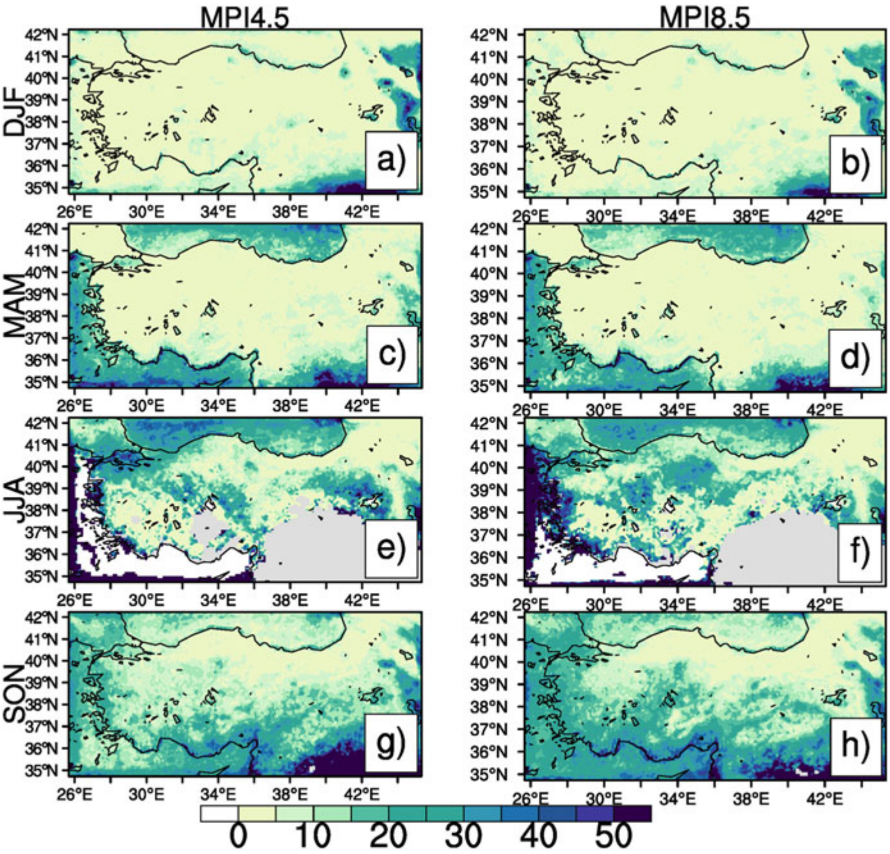

Fig. 14.11 Projected seasonal average percentage of days when the daily precipitation amount in the period of 2021–2050 is above the 90th percentile of the period of 1971–2000: (**a**) Winter (DJF), (**c**) Spring (MAM), (**e**) Summer (JJA), (**g**) Autumn (SON) under the RCP4.5 Scenario and (**b**) Winter (DJF), (**d**) Spring (MAM), (**f**) Summer (JJA), (**h**) Autumn (SON) under the RCP8.5

AI is defined as the ratio of total precipitation (P) to the potential evapotranspiration (PET) by the United Nations Environmental Programme (UNEP) (Turkes 1998, 1999):

$$AI = \frac{P}{PET} \tag{14.1}$$

Total precipitation amounts are directly provided by the RegCM's output, while the potential evapotranspiration values are empirically estimated by using the formula of Romanenko (1961). Romanenko's PET formula with its requirement for only two variables (i.e. mean air temperature (T_{mean}) and relative humidity (RH)) is

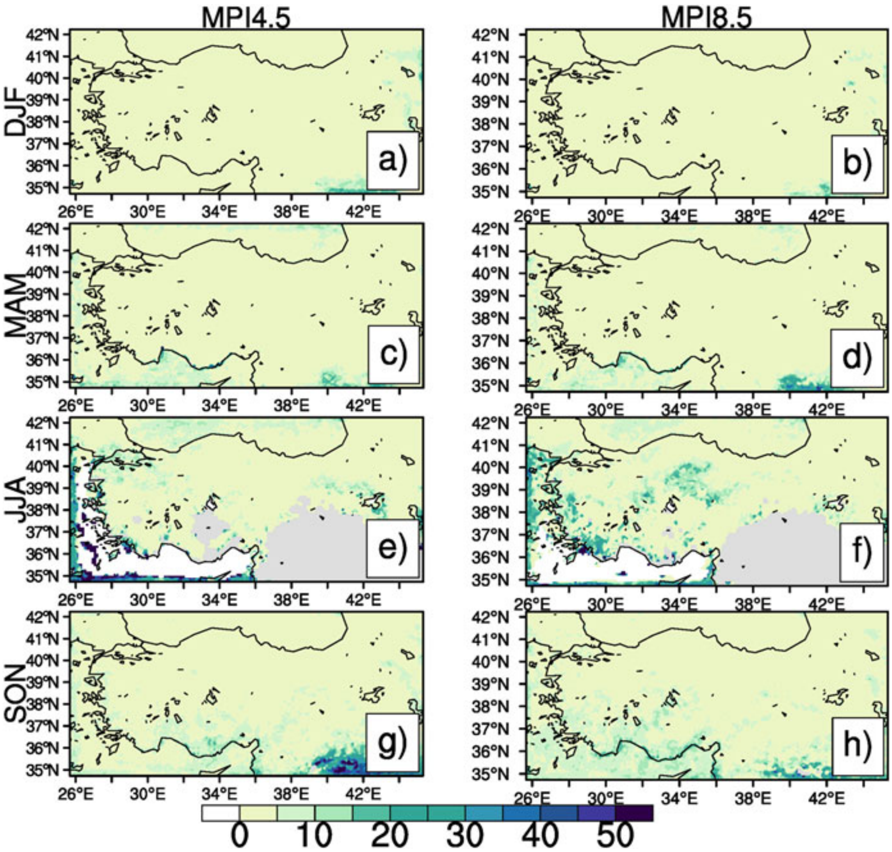

Fig. 14.12 Projected seasonal average percentage of days when the daily precipitation amount in the period of 2021–2050 is above the 95th percentile of the period of 1971–2000: (**a**) Winter (DJF), (**c**) Spring (MAM), (**e**) Summer (JJA), (**g**) Autumn (SON) under the RCP4.5 Scenario and (**b**) Winter (DJF), (**d**) Spring (MAM), (**f**) Summer (JJA), (**h**) Autumn (SON) under the RCP8.5

more practical than the other methods in the literature. Romanenko's PET formula is as follows (Romanenko 1961; Sahin 2012):

$$PET = 0.0018\ (25 + T_{mean})^2\ (100 - RH) \qquad (14.2)$$

Considering the AI classification modified by Turkes (2013), Turkey can be divided into seven categories: arid, semi-arid, dry sub-humid, moist sub-humid, semi-humid, humid & very humid, hyper humid (Table 14.1).

According to the map of the aridity index drawn for the reference period (1971–2000), except for a very small portion of arid lands (0.06%), there are no hyperarid or drylands experiencing the desert-like conditions in Turkey (Fig. 14.13). However, as previously stated by Turkes (2010, 2012b, c, 2013), in Turkey, there are semi-arid,

Table 14.1 Modified version of aridity index classification for the climate of Turkey (Turkes 2013)

Aridity index	Classification
< 0.20	Arid
0.20–0.50	Semi-arid
0.50–0.65	Dry sub-humid
0.65–0.80	Moist sub-humid
0.80–1.00	Semi-humid
1.00–2.00	Humid, very humid
> 2.00	Hyper-humid

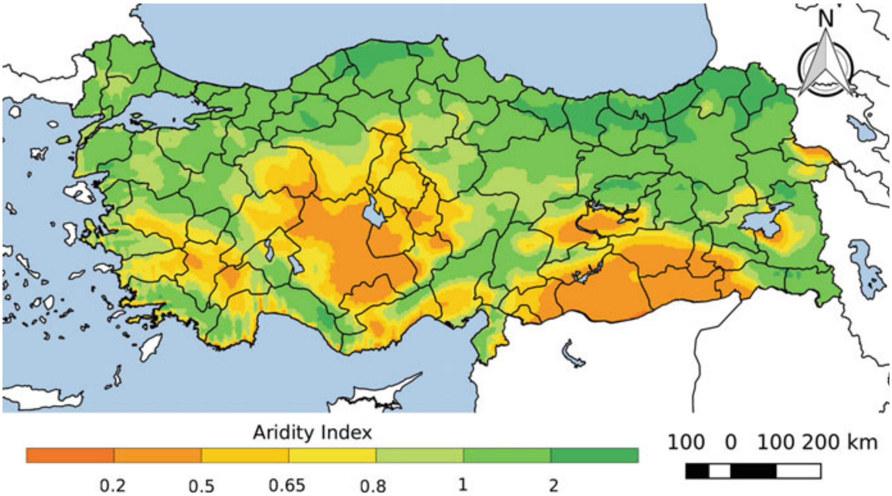

Fig. 14.13 Geographical distribution of AI for the reference period (1971–2000)

dry subhumid, and moist subhumid regions, which are prone to desertification or can be impacted by the desertification at different severity levels. Konya Plain in the Central Anatolia Region, Sanliurfa, Mardin, the eastern part of Gaziantep, southern parts of Diyarbakir and Batman, the western part of Sirnak in the Southeastern Anatolia Region, some parts of Malatya and Elazig in the valley of the upper Euphrates river, a small area in Denizli and Burdur in the Southwestern Anatolia Region, and Igdir province in the Eastern Anatolia Region have semi-arid climate conditions. The Northeastern Black Sea Region and some parts in the western Black Sea Region are hyper-humid areas in Turkey for the period of 1971–2000. Except for these arid and hyper-humid regions, the majority of the areas in Turkey are classified as semi-humid, humid, and very humid.

When the projection results are evaluated for the near future, Turkey's future is expected to go towards more arid conditions in both scenarios (Figs. 14.14 and 14.15). According to the RCP4.5 scenario, it is seen that areas where semi-arid conditions prevail in the past will expand slightly in the near-future (Table 14.2). That is, it is projected that semi-arid and dry sub-humid conditions will dominate in

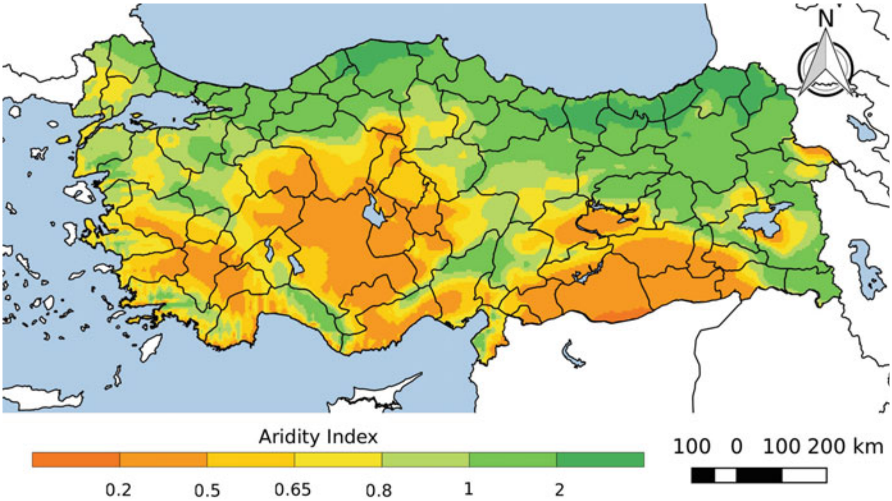

Fig. 14.14 Geographical distribution of projected AI for the future period (2021–2050) under RCP4.5 scenario

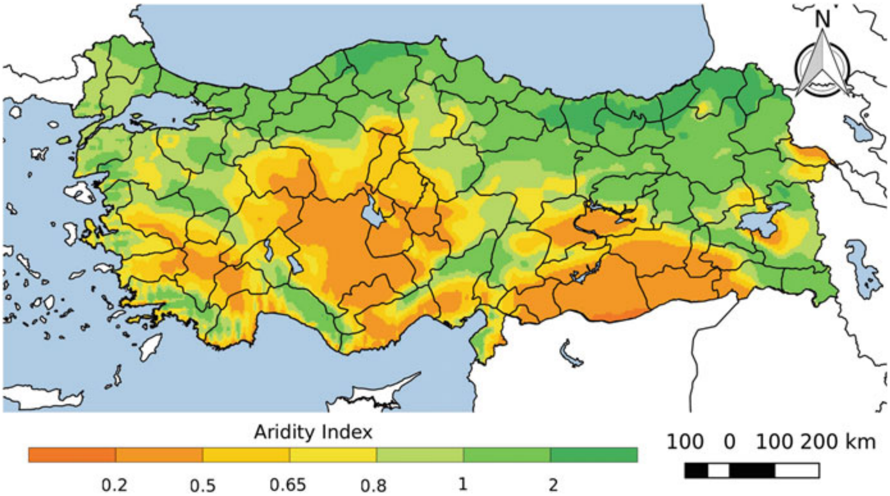

Fig. 14.15 Geographical distribution of projected AI for the future period (2021–2050) under RCP8.5 scenario

the future period (2021–2050) over the Central Anatolia Region, the Southeastern Anatolia Region, and the inner Aegean Region (Fig. 14.14). It is also expected that moist sub-humid conditions will prevail throughout Thrace's Edirne and Tekirdag provinces. Similar results are obtained according to the RCP8.5 scenario, as those in the RCP4.5 scenario, but the severity of the aridity will be slightly less in the 2021–2050 period under the RCP8.5 scenario (Fig. 14.15). For example, according to the

Table 14.2 Comparison of arid and humid areas in Turkey from past to near-future

Aridity classification	Area (%) for reference period (1971–2000)	Area (%) for future period (2021–2050) under RCP4.5 scenario	Area (%) for future period (2021–2050) under RCP8.5 scenario
Arid	0.06	0.29	0.26
Semi-arid	12.86	21.58	19.50
Dry sub-humid	11.77	14.44	14.07
Moist sub-humid	11.32	13.36	12.51
Semi-humid	16.71	16.67	18.24
Humid, very humid	40.44	28.67	30.63
Hyper-humid	6.85	4.98	4.79

RCP4.5 scenario, the conditions that are moist sub-humid in Edirne and Tekirdag provinces become humid and very humid under the RCP8.5 scenario.

According to the classification of aridity index, calculated based on the outputs obtained from the climate model, it is projected that the humid and very humid areas prevalent in the 1971–2000 period will substantially diminish in the future under both scenarios (i.e. RCP4.5 and RCP8.5), whereas especially the semi-arid areas will be more extended (Table 14.2). In other words, with climate change, it is anticipated that the areas prone to desertification will be widened, while the areas in which desertification does not occur, especially in the Black Sea Region, will be lessened. However, it is expected that the semi-humid regions that are inclined to desertification in deteriorating conditions will remain almost the same due to the RCP4.5 scenario and will increase a little according to the RCP8.5 scenario.

14.6 Conclusions

In this chapter, impacts of climate change on mean precipitation climatology, precipitation extremes and aridity conditions for Turkey are projected using the regional climate model RegCM4.4. Regional climate model is driven by MPI-ESM-MR global climate model for the period of 2021–2050. The MPI-ESM-MR global climate model is chosen as this model represents the climatology of the Eastern Mediterranean Basin more accurately than comparable global models. First, the ability of the RegCM4.4 regional climate model to reproduce the observed climatology is evaluated for four climatological seasons for the period of 1971–2000 by comparing outputs of regional model with the CRU dataset. Results show that the RegCM regional model's capacity in reproducing the observed temperature and precipitation climatology is reasonable. The CRU dataset is created using meteorological data from observation stations. Prior to year 2000, these stations were not wide spread and were also prone to human reading errors. There are few stations from Turkey, which are included in the CRU dataset. Therefore, a perfect correspondence between the model outputs and the CRU dataset should not be expected. Even under these circumstances, the model outputs give reliable results when compared to the CRU dataset. Also, it must be mentioned that the main difference between the climate model outputs and the observation datasets come from the physics used in the global climate models. Regional climate models used to downscale the climate variables decrease the differences between the model outputs and the observations.

The MPI-ESM-MR global model with RCP4.5 and RCP8.5 emission scenario outputs is used as forcing data for the regional climate model RegCM4.4 for the near future (2021–2050) in order to project changes in precipitation climatology, extremes and aridity conditions. According to model results of future projections, there will be a decrease in precipitation amounts over almost all parts of Turkey. Drier conditions will likely occur over the most part of Turkey, which is already arid and semi-arid.

In the near future (2021–2050), most of the drier conditions will be observed in the western and southern parts of Turkey and especially during the winter season. This is to be expected as the western and southern parts of the country normally get most of the precipitation in the winter season. As rain is infrequent in the summer months, a relative decrease in the precipitation amounts will not be readily visible in the model outputs. It should also be remarked that the northern and the northwestern part of the country does not lose much of the precipitation in any season, and some slight increase in the winter season can be observed along the Black Sea coastal region. Even though the uncertainty in the climate models can be considered slightly high, there might be some good news for the Central Anatolia region for the winter months, especially in the RCP4.5 emission scenario.

For Turkey, the difference between the precipitation outputs of RCP4.5 and RCP8.5 scenarios for the near future (2021–2050) is clearly observable. Common sense suggests that precipitation should decrease more in the worse scenario (RCP8.5) than the better scenario (RCP4.5). However, the model outputs show that the opposite can be true. In Turkey, higher temperatures lead to more evaporation, and, in turn, this leads to more precipitation. In the far future of the climate models (2071–2100), this behavior will change as the atmospheric pressure systems will shift, causing a more severe drying in our region.

The used models produce outputs every 3 min. But, to be able to compare the data with observations, average (temperature) or sum (precipitation) of the data obtained from the models is needed. Therefore, important information regarding the strength of the precipitation events is lost. The situation for Turkey is not the loss in the total amount of precipitation but the change in the distribution of the precipitation pattern. The distribution pattern of the precipitation events changes in such a way that both extreme precipitation events and also prolonged droughts in the region occur. This change in precipitation patterns is not unique to Turkey, but it is certainly a result of global climate change.

Therefore, the projected drought (decrease in precipitation) conditions will very likely affect Turkey, which already has a mostly arid and semiarid climate and environment, and this makes Turkey extremely vulnerable to climate change, particularly to increased droughts. As the rainstorms also come as extreme events, the water holding capacity of the upper layers of the soil is negatively affected. Heavy rains after long drought events also lead to soil erosion in the region.

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