CLIMATE CHANGE PROJECTIONS FOR TURKEY WITH NEW SCENARIOS

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Abstract: *A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. Other terms that have been used as synonyms for scenario are "characterisation", "storyline" and "construction" (IPCC, URL). Scenarios of potential future anthropogenic climate change, underlying driving forces, and response options have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC). They should not be considered forecasts or absolute bounds. RCPs are representative of plausible alternative scenarios for the future but are not predictions or forecasts of future outcomes. No RCP is intended as a "best guess," most likely, or most plausible projection (IPCC, 2007). The name "representative concentration pathways - RCP's" was chosen to emphasize the rationale behind their use. RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, which is of interest, but also the trajectory that is taken over time to reach that outcome. They are representative in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics. In this study, we tried to reveal the possibilities of future climate change for Turkey in a region encompassing our country with the regional climate model. HadGEM2-ES Global Circulation Model outputs which is produced with RCP4.5 and RCP8.5 concentration scenarios have been used in the study, which are used CMIP5 project and situated in the IPCC 5th Assessment Report. Temperature and precipitation projections for Turkey have been produced from these outputs, for a domain with 20 km resolution that is include our country and for a period between the years 2013-2099, using by RegCM4.3.4 regional climate model and with dynamic downscaling method.*

***Keywords*:** IPCC, RCP, *HadGEM2-ES, RegCM, Climate Change*

1. INTRODUCTION

The importance of climate in human life is associated with positive or negative effects of the climate in social and economic life and how it affects (Demir et al., 2013). To sustain the lives of people under better conditions and more soundly, many institutions and organizations, both as national and international, central and local governments and non-governmental organizations have made efforts in different ways in order to determine changes that may occur in climate and the impact of these changes correctly.

The most important of these efforts are climate modelling studies. Variables representing environmental conditions may include in the model in more detail in conjunction with the development of technology. From the 1970s climate models began to be used with the proliferation of the use of computers for scientific purposes. In the first climate model studies, climate was modelled according to only the atmosphere and observed parameters in the atmosphere. In parallel with technological and scientific developments, land surface, oceans, sea ice, sulphate aerosols, carbon cycle, atmospheric chemistry and dynamics of vegetation and other factors have been new parameters that are important inputs to climate models.

With the development of science and technology studies on climate change has been put into a more meaningful effort with the guidance of the IPCC which is created association under the name of International Panel on Climate Change after 1990 years. Synergy of this association, IPCC studies results, was carried out with a certain period.

Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the Coupled Model Intercomparison Project (CMIP) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs)(CMIP,URL). CMIP provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyse GCMs in a systematic fashion, a process which serves to facilitate model improvement. Virtually the entire international climate modelling community has participated in this project since its inception in 1995.

Climate models are the primary tools available for investigating the response of the climate system to various forcings, for making climate predictions on seasonal to decadal time scales and for making projections of future climate over the coming century and beyond (IPCC,2013). RCMs are limited-area models with representations of climate processes comparable to those in the atmospheric and land surface components of AOGCMs, though typically run without interactive ocean and sea ice. Regional Climate Models (RCMs) are applied over a limited-area domain with boundary conditions either from global reanalyses or global climate model output. RCMs are often used to dynamically ‘downscale’ global model simulations for some particular geographical region to provide more detailed information (IPCC, 2013; Laprise, 2008; Rummukainen, 2010). By contrast, empirical and statistical downscaling methods constitute a range of techniques to provide similar regional or local detail. Parameterizations are included in all model components to represent processes that cannot be explicitly resolved; they are evaluated both in isolation and in the context of the full model. Atmospheric models must parameterize a wide range of processes, including those associated with atmospheric convection and clouds, cloud-microphysical and aerosol processes and their interaction, boundary layer processes, as well as radiation and the treatment of unresolved gravity waves.

HadGEM2 stands for the Hadley Centre Global Environment Model version 2. The HadGEM2 family of models comprises a range of specific model configurations incorporating different levels of complexity but with a common physical framework. The HadGEM2 family includes a coupled atmosphere-ocean configuration, with or without a vertical extension in the atmosphere to include a well-resolved stratosphere, and an Earth-System configuration which includes dynamic vegetation, ocean biology and atmospheric chemistry. Members of the HadGEM2 family will be used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The ENSEMBLES project also uses members of this model family. The standard atmospheric component has 38 levels extending to ~40km height, with a horizontal resolution of 1.25 degrees of latitude by 1.875 degrees of longitude, which produces a global grid of 192 x 145 grid cells. This is equivalent to a surface resolution of about 208 km x 139 km at the Equator, reducing to 120 km x 139 km at 55 degrees of latitude. A vertically-extended version, with 60 levels extending to 85km height, is also used for investigating stratospheric processes and their influence on global climate. The oceanic component utilizes a latitude-longitude grid with a longitudinal resolution of 1 degree, and latitudinal resolution of 1 degree between the poles and 30 degrees North/South, from which it increases smoothly to one third of a degree at the equator, giving 360 x 216 grid points in total, and 40 unevenly spaced levels in the vertical (a resolution of 10m near the surface)(MetOffice, URL).

Climate is the average weather conditions experienced in a particular place over a long period. Climatological normals are averages for consecutive periods of 30 years which are calculated from climatological data (Demircan et al. 2013). Using climate normals are very important tool to provide a standard base for preparing global assessment and climate monitoring studies. The reference period of Climate; 1961-1990, 1971-2000 and 1981-2010 as climate normals are used by scientists, national climate services and international institutions and organizations in international, national and regional-based climate monitoring, climate trends, climate change and climate modelling studies.

Climate change prediction studies provide the main data input in all sectors to be made in planning for adaptation, mitigation and prevention efforts ie. future planning of stakeholders must be based on climate and climate model outputs. Under climate change context, different scenarios of global climate models to be made for future must be downscaled to form a high resolution data set for Turkey and vicinity. These data are become available as sectorial and are used as the basis by sector for their planning in adaptation, mitigation and prevention activities will improve the accuracy and success of their studies.

2. METHODS

The work presented involves the reproduction of climate parameters with a higher resolution by using a regional climate model (RegCM4.3.4) and downscaling method from outputs of HadGEM2-ES Global Circulation Model which is prepared for the IPCC 5th Assessment Report and produced on the basis of RCP4.5 and RCP8.5 scenarios.

2.1 Representative Concentration Pathways – RCP’s

"Experts Meeting" with broad participation was organized by the IPCC in September 2007 for a new approach for climate change scenarios to be used in the IPCC 5th Assessment Report and in this context; it has been decided to be created a set of new emission/concentration scenarios. In accordance with this decision, 4 pcs of Representative Concentration Pathways (RCP's) were determined which have specified characteristics (Table 1).

Table 1. Types of Representative Concentration Pathways (RCP’s).

Name of RCP’s	Radiative Forcing	Time	Pathway shape	Concentration (ppm)	Emissions (Kyoto Protocol’s greenhouse gases)
RCP 8.5	> 8.5 W/m2	in 2100	Rising	> ~1370 CO2-eq in 2100	Rising continues until 2100.
RCP 6.0	~6.0 W/m2	at stabilization after 2100	Stabilization without overshoot	~850 CO2-eq (at stabilization after 2100)	Decline in the last quarter of century
RCP 4.5	~4.5 W/m2	at stabilization after 2100	Stabilization without overshoot	~650 CO2-eq (at stabilization after 2100)	Decline from the mid-century
RCP3-PD*	~3.0 W/m2	peak at before 2100 and then decline	Peak and decline	peak at ~490 CO2-eq before 2100 and then decline	Decline in the first quarter of century

Based on IPCC, 2007

2.2 Global Models and Data Sets

This study covers obtained results until now from a project which name is "Climate Projections for in and around of Turkey" and is still on-going. In this regard, "Climate Projections for Turkey" with different global models and scenarios has still been continued to study. In this context, RCP4.5 and

RCP8.5 scenarios (2013-2099) and the 30-year reference period (1971-2000) of the global model HadGEM2-ES's data were used. In model's control test, regional model was run for the period of 1971-2000 and output's result was compared with other global observation data sets (CRI, Udel, Udel-c) (Table 2).

Table 2. Data Sets.

GCM	RCM	Sensitivity Analysis Data	Period
HadGEM2-ES	RegCM4.3.4	• HadGEM2-ES RF(1971-2000) • CRU (1971-2000) • UDEL (1971-2000) • UDEL-c (1971-2000)	2013-2099

2.3 Dynamic Downscaling: RegCM4

RegCM4 were used in the study which is developed by International Centre for Theoretical Physics in Italy (ICTP)(Giorgi et al 1993a,b). This model is a limited area atmospheric models that is consisting of the basic equation, hydrostatic, compressible and sigma pressure levels. RegCM4's model physic uses BATS ground surface model (Dickinson et al. 1993), non-local boundary layer diagram (Holtslag et al. 1990), the radiation scheme of the NCAR CCM3 (Kiehl et al. 1996), parameterizations for ocean surface fluxes (Zeng et al., 1998), the explicit moisture scheme of (Hsie et al. 1984), a large-scale cloud and precipitation scheme which accounts for the subgrid-scale variability of clouds (Pal et al., 2000) and various options for cumulus convection (Anthes, 1977; Grella, 1993; Emanuel and Zivkovic-Rothman, 1999).

For projection study has been used cumulus convection parameterization of Emanuel on the land and Grell (1993) on the sea as convective precipitation scheme. A domain with 20 km horizontal resolution which has 130x180 grid-scale and 18 pcs sigma level has been used for model simulations (Figure 1).

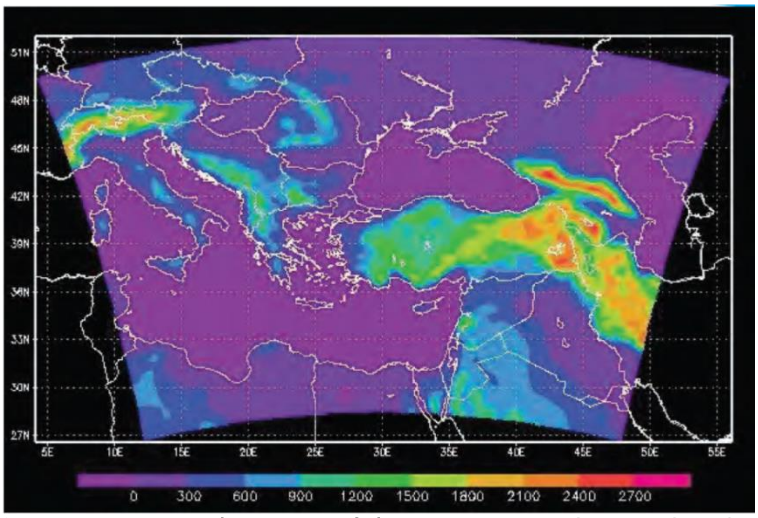

Figure 1. Topography image of domain area in RCM (RegCM4.3.4)

2.4 The Sensitivity and Control Tests

Using of reference period data sets referred to in Table 1, the sensitivity of the model was compared based on seasonal and general average (Table 3, Table 4).

Table 3. Comparing of the average temperature of the reference period (1971-2000) and different observation data sets as seasonal basis.

Temperature (°C)	RCM	CRU	UDEL	RAW
WINTER	0.436	0.561	0.258	1.762
SPRING	8.294	9.712	9.503	9.867
SUMMER	20.792	20.859	20.834	20.763
AUTUMN	10.412	12.480	12.177	12.349
AVERAGE	**9.987**	**10.906**	**10.694**	**11.190**

When average temperature results that is obtained by downscaling from HadGEM2-ES global model reference period (1971 to 2000) data has compared with other observation data sets, in particular results of winter and summer, model's data are seen that overlap with observation data. Temperature values of model are lower about 1.5°C according to observation data sets in spring and autumn. Considering the overall average in Turkey, model's result is lower about 0.71-0.92°C according to CRU and UDEL's observation data sets.

Table 4. Comparing of the daily precipitation of the reference period (1971-2000) and different observation data sets as seasonal basis.

Precipitation (mm/gün)	RCM	CRU	UDEL	UDEL-C	RAW
WINTER	2.159	2.126	2.064	2.452	2.764
SPRING	2.622	1.974	1.881	2.101	2.874
SUMMER	0.947	0.686	0.653	0.733	0.952
AUTUMN	1.830	1.333	1.347	1.497	1.858
AVERAGE	**1.886**	**1.531**	**1.487**	**1.697**	**2.107**

When daily precipitation results that is obtained by downscaling from HadGEM2-ES global model reference period (1971 to 2000) data has compared with other observation data sets, in particular the result of winter, model's data is seen that overlap with observation data. Daily precipitation results of model are higher than observation data sets in spring and autumn. Considering the overall average in Turkey, model's result is higher about 23% according to other observation data sets.

3. HadGEM2-ES PROJECTIONS RESULTS FOR TURKEY

In this study, we tried to reveal the possibilities of future climate change for Turkey in a region encompassing our country with the regional climate model. HadGEM2-ES Global Circulation Model outputs which is produced with RCP4.5 and RCP8.5 concentration scenarios have been used in the study, which are used CMIP5 project and situated in the IPCC 5th Assessment Report. Temperature and precipitation projections for Turkey have been produced from these outputs, for a domain with 20 km resolution that is include our country and for a period between the years 2013-2099, using by RegCM4.3.4 regional climate model and with dynamic downscaling method. The future time period 2013-2099 is separated three groups respectively 2013-2040, 2041-2070 and 2071-2099. Seasonal mean values were obtained for these three periods. Differences between reference period (1971-2000) and these periods were calculated for temperature and precipitation.

3.1 Temperature and Precipitation Projections According to RCP4.5 Scenario

Temperature and precipitation values were obtained from RCP4.5 scenario of HadGEM2-ES global climate model with dynamic downscaling method for project domain. Then differences between reference period (1971-2000) and these periods were calculated for temperature and precipitation. Differences values of temperature and precipitation are visualized as seasonally for all periods. In generally, temperature difference values tend to increase and precipitation difference values tend to decrease from now to until the end of the century (Figure 2, 3).

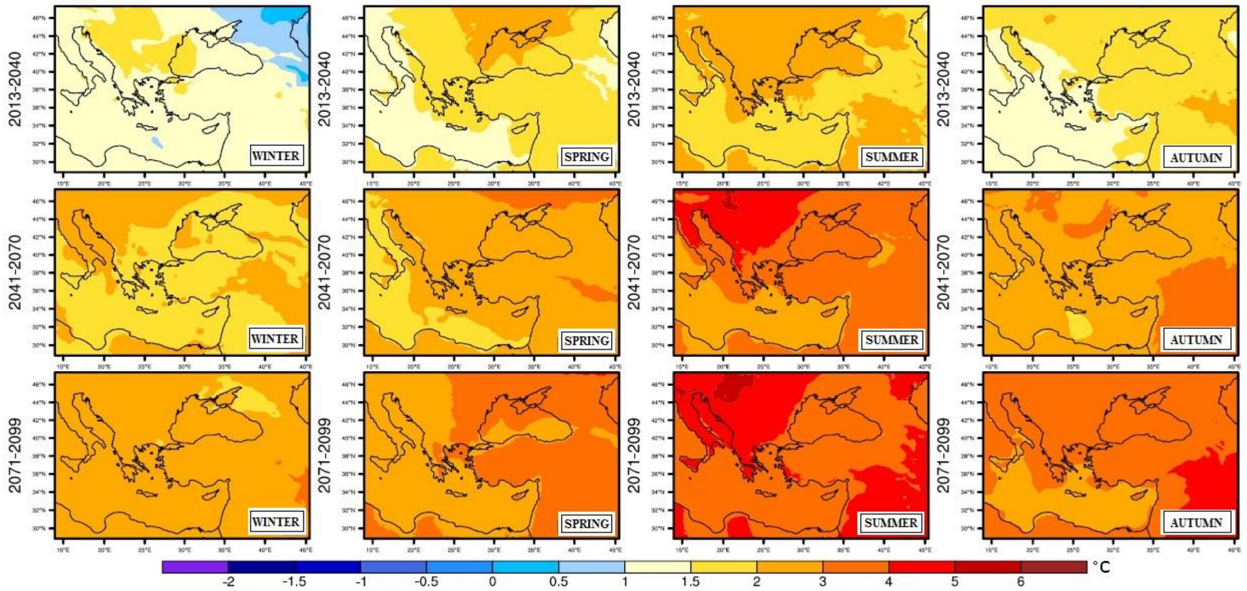

Figure 2. Temperature projections according to RCP4.5

In the first period (2013-2040), it would be an increase in generally about 1.5-2°C in temperatures. It would be an increase about 2-3°C in summer temperature, especially in Marmara and west of Black Sea Region. In second period (2041-2070), It would be an increase about 2-3°C in spring and autumn temperatures. It would be an increase up to 4°C in the summer temperature. In last period (2071-2099), it would be an increase about 2°C in winter temperature and 3°C in spring and autumn temperatures. It would be an increase up to 5°C in summer temperature in the Southeast Anatolia Region and coastal part of the Aegean Region.

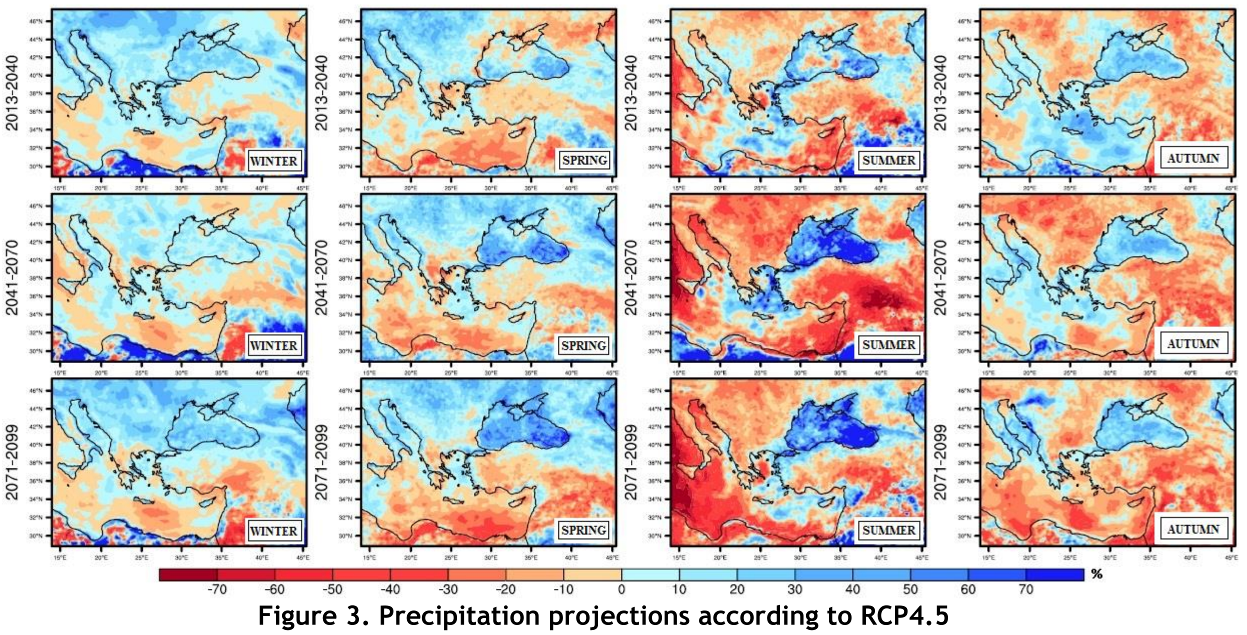

Figure 3. Precipitation projections according to RCP4.5

In first period (2013-2040), it would be an increase in precipitation during the winter months in the coast part of the Aegean, middle part of the Black Sea and East Anatolia Regions; unfortunately it is expected to decrease about 20% in the precipitation in the spring in a large part of the country. In second period (2041-2070), it would be a decrease about 20% in winter precipitation in East Anatolia, Southeast Anatolia and central and eastern parts of Mediterranean region. It would be a decrease around 30% in summer season in Eastern Anatolia where summer rainfall is important. In the autumn precipitation, it would be a decrease except coastal part of the Aegean Region and a small part of Central Anatolia Region. In last period (2071-2099), it would be an increase about 10% especially along coastal line except South East Anatolia Region. It would be a decrease about 20% in spring precipitation except coastal part of the Aegean Region, west and east part of Black Sea Region and northern part of East Anatolia Region. It would be a decrease up to 40% in summer precipitation except coastal part of the Aegean, the Marmara and the Black Sea Regions. It would be a decrease in autumn precipitation throughout the country.

3.2 Temperature and Precipitation Projections According to RCP8.5 Scenario

Temperature and precipitation values were obtained from RCP8.5 scenario of HadGEM2-ES global climate model with dynamic downscaling method for project domain. Then differences between reference period (1971-2000) and these periods were calculated for temperature and precipitation. Differences values of temperature and precipitation are visualized as seasonally for all periods. In generally, temperature difference values tend to increase and precipitation difference values tend to decrease from now to until the end of the century (Figure 2, 3).

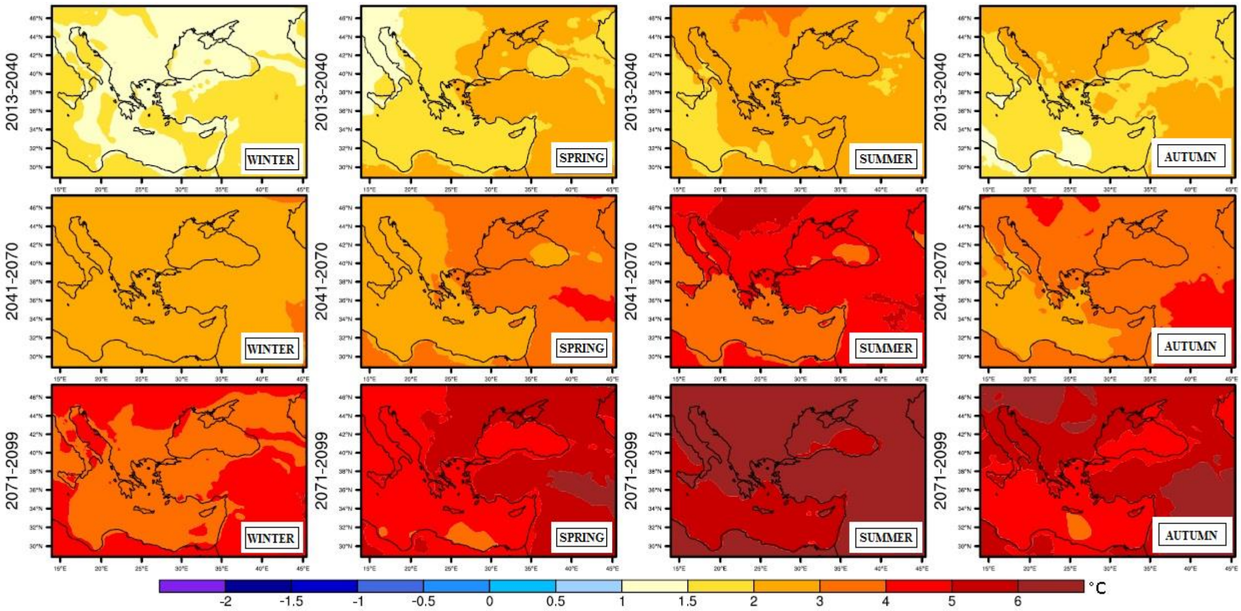

Figure 4. Temperature projections according to RCP8.5

In the first period (2013-2040), it would be an increase about 3°C especially in spring and summer temperatures. In the second period (2041-2070), it would be an increase about 2-3°C in the winter temperature, about 3-4°C in autumn and spring temperatures and about 5°C in summer temperature. In the last period (2071-2099), it would be an increase about 3-4°C in west of Trabzon and Mersin line, about 4-5°C in east of Trabzon and Mersin line in winter temperature. It would be an increase about 6°C in spring and autumn temperature s especially in South East Anatolia Region. It would be an increase exceeding 6°C in summer temperature throughout the country.

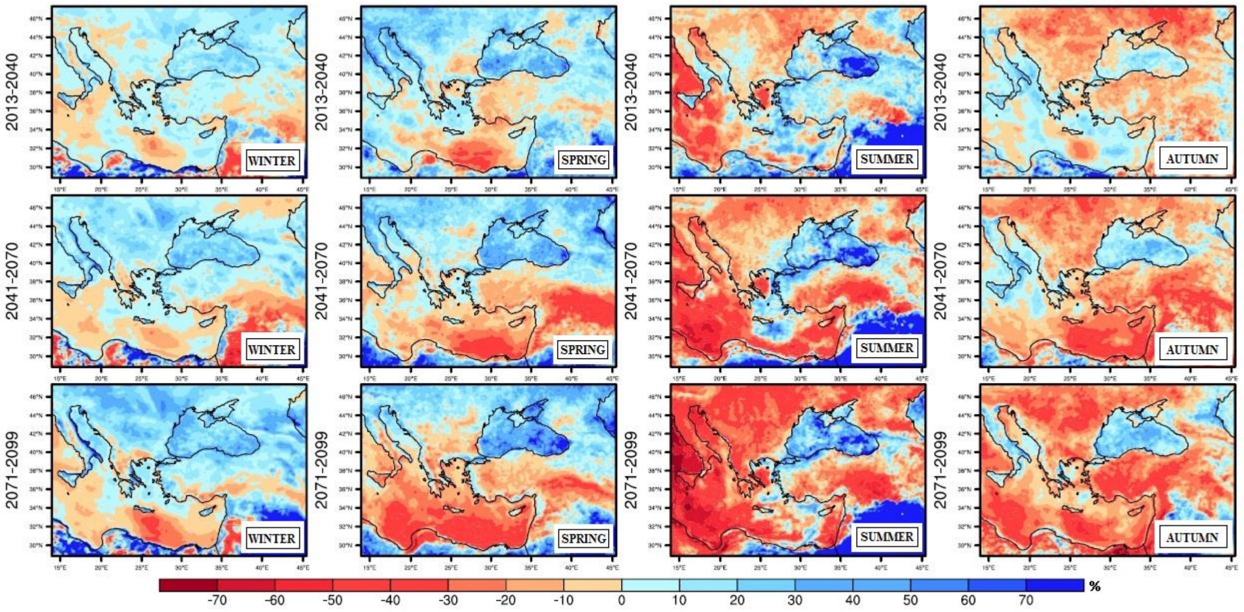

Figure 5. Precipitation projections according to RCP8.5

In first period (2013-2040), it would be an increase in precipitation during the winter months except west part of the Marmara, east part of the Mediterranean, southeast part of the Central Anatolia and west part of the Southeast Anatolia Regions. It would be a decrease in spring precipitation in west of Mersin-Ordu line. It would be an increase about 40% in summer precipitation except west part of the Mediterranean Region. It would be a decrease in autumn precipitation throughout the country. In second period (2041-2070), it would be an increase in precipitation during the winter months except south part of Anatolia. It would be a decrease in spring season except west part of the Aegean, west and east part of the Black Sea and northern part of East Anatolian Regions. It would be a decrease about 50% in summer precipitation throughout the country except west and east part of the Black Sea, coastal part of the Aegean and the Marmara Regions. In the autumn precipitation, it would be a decrease throughout the country in generally. In last period (2071-2099), it would be an increase in precipitation during the winter months except south part of Anatolia. It would be a decrease about 20% in spring precipitation except coastal part of the Aegean Region, west and east part of Black Sea Region and northern part of East Anatolia Region. It would be a decrease in summer precipitation except coastal part of the Aegean, the Marmara and the Black Sea Regions. It would be a decrease up to 50% in autumn precipitation throughout the country.

Table 5. Summary table: Comparing of temperature projections range between RCP4.5 and RCP8.5 Scenario.

	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85
Period	**Winter**		**Spring**		**Summer**		**Autumn**	
2013-2040	1,5-2	1-2	1,5-2	2-3	2-3	1,5-3	1,5-2	1,5-3
2041-2071	1,5-3	2-3	2-3	3-5	2-4	4-5	2-4	3-5
2071-2099	2-3	3-5	2-4	4-6	3-5	5-6	3-5	4-6

Table 6. Summary table: Comparing of precipitation projections range between RCP4.5 and RCP8.5 Scenario.

	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85	RCP45	RCP85
Period	Winter		Spring		Summer		Autumn	
2013-2040	-10 - +20	-10 - +30	-20 - +20	-20 - +30	-30 - +40	-40 - +40	-30 - +10	-30 - +10
2041-2071	-30 - +30	-30 - +40	-40 - +20	-40 - +30	-50 - +60	-50 - +60	-40 - +10	-40 - +10
2071-2099	-20 - +30	-30 - +50	-50- +20	-50 - +30	-50 - +50	-50 - +60	-50 - +10	-50 - +10

4. CONCLUSIONS

According to the outputs obtained from the projections; the temperature increase is limited up to 3°C in in the first period of 2013-2099 years. Especially in the last period (2070-2099), it is noteworthy increase in summer temperatures about 4-5°C in Aegean coast and South Eastern Anatolia according to RCP4.5 and up to 6°C in summer season throughout the country according to RCP8.5. For precipitation, it is noted increase in winter precipitation in most of country according to both RCP in all periods. It would be a decrease in generally in spring precipitation except coastal and north-eastern part of country according to both RCP in all periods. It would be a decrease in generally in summer precipitation except coastal and north-eastern part of country and first period of RCP8.5 according to both RCP in all periods. It would be a decrease in generally in autumn precipitation except some part of country according to both RCP in all periods.

"Climate Projections for Turkey" is a project which is made by an official institution with its own resources and personnel for the first time in Turkey for new models and scenarios. This study covers obtained results until now from a project is still on-going. In this regard, "Climate Projections for Turkey" with different global models and scenarios has still been continued to study. In this context, RCP4.5 and RCP8.5 scenarios (2013-2099) of two different models will be downscaled in this project. It is initiated to get six different models output at end of the project.

Climate change prediction studies provide the main data input in all sectors to be made in planning for adaptation, mitigation and prevention efforts ie. future planning of stakeholders must be based on climate and climate model outputs. Under climate change context, different scenarios of global climate change to be made for future must be downscaled to form a high resolution data set for Turkey and vicinity. These data are become available as sectorial and are used as the basis by sector for their planning in adaptation, mitigation and prevention activities will improve the accuracy and success of their studies.

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