GLOBAL PROJECTIONS AND CHANGE TURKEY

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Summary

In the last century, the effects of climate change caused by the increasing greenhouse effect as a result of human activities have started to be felt intensely in our lives. Assessing the potential impacts of climate change on environmental and natural systems is crucial for adaptation to and mitigation of climate change. Therefore, how the climate will change for different scenarios should be examined and strategies for coping with climate change should be forward in the light of these expectations. The aim of this paper is to present the global climate change and its reflections on Turkey in particular. In this context, climate scenarios and climate models on which future climate projections are based will be examined. Spatial and temporal changes of global average temperatures and precipitation within the Common Socio-Economic Route scenarios of global modeling studies will be presented. Future climate projections for Turkey produced for medium and high emission scenarios using regional climate models will be evaluated.

Keywords
Climate projectionsSSP scenariosRCP scenariosRegional climate modelsTurkey

GLOBAL CLIMATE PROJECTIONS AND CLIMATE CHANGE IN TURKEY

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Abstract

The effects of climate change induced by increasing greenhouse effect due to the human activities have been intensely started to touch our daily lives. Evaluation of the potential effects of climate change on environmental and natural systems is very important for adaptation and mitigation of the effects of climate change. For this reason, how the climate will change within different emission scenarios should be examined and strategies to cope with climate change should be put forward in the light of these expectations. The aim of this article is to reveal the change of climate on a global scale and its reflections especially on Turkey. In this context, climate scenarios and climate models on which future climate projections are based on, will be examined. Global climate model projections under different scenarios of Shared Socio- Economic Pathways will be presented by focusing on spatial and temporal variations of global average temperatures and precipitation. Future climate projections on Turkey produced for medium and high emission scenarios using regional climate models will be discussed.

Keywords
Climate Projections, SSP scenarios, RCP scenarios, Regional climate models, Turkey

1. Introduction

Climate has a significant impact on life on Earth as well as human activity. Temperature and rainfall determine the type of plants that grow best in a given area, and summer and winter temperatures, as well as the likelihood of flooding, determine the design and location of houses. A late frost or a severe hailstorm can ruin entire crops. Since the beginning of humanity, people have had to cope with such climatic extremes and, if possible, adapt to them.

Throughout the history of the world, the climate has never remained constant and the global average temperature of the world has varied within the range of 10ºC. Within this 10ºC temperature range, ice ages have occurred in the world and temperate climatic conditions have been realized between these ice ages. Therefore, the 1.1ºC increase in global average temperatures in the last century compared to the pre-industrial revolution indicates an extremely rapid climate change. Climate has changed and continues to change as a result of natural and anthropogenic radiative forcings altering the interactions between the components of the Earth's climate system: the atmosphere, oceans, ice sphere, earth and biosphere, which occur at very different spatial and temporal scales. The natural variability of climate depends on changes in Earth's orbital parametersvolcano eruptions and solar activity. These increases over the last century may seem small to people other than climate scientists, but changes in the central parts of the continents (agriculture is concentrated) are typically twice the global average change, while changes at higher latitudes are 3 to 4 times the global average (with major impacts on tundra, permafrost, boreal forests and sea ice). Furthermore, small changes in global mean surface temperature correspond to large changes in climate patterns that affect human activities and ecosystems (Schneider et al., 2014).

The popular term global warming is a misnomer and refers to a uniform change in temperature. In reality, the global climate is changing unevenly across geographic, economic and social dimensions. Current climate change is rapid compared to historical climate change, but it is also rapid in terms of the adaptation times of ecosystems and human society. It is affecting a wide range of critically important climate phenomena, including temperature as well as precipitation, atmospheric moisture, soil moisture, atmospheric circulation, storms, snow-ice cover and ocean currents. And its impacts are undoubtedly increasingly threatening human well-being.

Global climate change and its impacts have been documented in thousands of scientific reports examining climate events in many parts of the world. While natural processes influence climate and climate change on both short and long time scales, humans and human activities are the dominant driver of this extraordinarily rapid climate change, which has steadily increased since the beginning of the Industrial Revolution, and scientific evidence in recent decades supports this assertion. Indeed, each report of the Intergovernmental Panel on Climate Change (IPCC) increases confidence that the climate change observed over the last century is human-induced (IPCC, 2007; 2013; 2021).

Changing the composition of the atmosphere through human impacts changes the global climate by increasing the atmospheric greenhouse effect. The exponential increase in the concentration of CO_2, the greenhouse gas in the atmosphere, from 280 ppm in the 1800s before the industrial revolution to around 415 ppm in 2022, as well as the increase in emissions of other greenhouse gases and the consequent warming trend of the world climate, has led many atmospheric scientists to investigate the response of the global climate to future increases. The IPCC 5th and 6th Review Reports, in which global climate studies were compiled, revealed that the air temperature over land has increased more than over the oceans, the last forty years have been much warmer than the past records, and the 2000s were the warmest years on record, based on analyses based on independent data sets. Compared to the period 1850-1900, the increase in global temperature between 2001-2020 between 0.95ºC and 1.20ºC, with an average increase of 1.01ºC. As a matter of fact, 16 of the 17 hottest years were observed after the 2000s and the 5 hottest years were as 2016, 2020, 2019, 2015 and 2017, respectively. However, although the IPCC (2013) report indicates a change of less than 10% in temperature increase without correction for the urban heat island effect in temperature records, it also pointed out that the effects of the urban heat island in rapidly developing and growing cities and land use changes in some regions may increase on regional trends. The most important emphasis of the latest report is confirmation of the human role in climate change.

The aim of this article is to present the change in climate change and its impacts on Turkey in particular. First, the climate scenarios on which future climate projections are based will be presented, then the expectations of climate change globally under different scenarios and the effects of climate change based on studies conducted in Turkey will be presented.

2. Climate Scenarios

There are several different climate emission scenarios developed by scientists and policy makers to understand and predict the potential impacts of climate change. These scenarios are based on different assumptions about how human activities, such as the burning of fossil fuels, will affect the concentration of greenhouse gases in the atmosphere.

To help understand the potential impacts of different levels of greenhouse gas emissions on climate, the IPCC has developed a set of scenarios known as Representative Concentration Pathways (RCPs). The RCPs are based on four different pathways for future emissions, ranging from relatively low to relatively high emission levels. Each RCP is characterized by a specific greenhouse gas concentration in the atmosphere, measured in parts per million (ppm) of CO_2 equivalent (CO_2e) (van Vuuren et al., 2011).

RCP2.6: a low emissions scenario in which greenhouse gas concentrations stabilize around 430 ppm CO_2e by the end of the century. This scenario aims to limit global warming to 2°C or less below pre-industrial levels.

RCP4.5: a medium emissions scenario in which GHG concentrations stabilize around 540 ppm CO_2e by the end of the century. This scenario is also consistent with the goal of limiting global warming to below 2°C, but requires more significant emission reductions than RCP2.6.

RCP6: Represents the scenario between the medium and high emissions scenario, where GHG concentrations stabilize around 630 ppm CO_2e by the end of the century. It is not consistent with the goal of limiting global warming to below 2°C, but would still result in lower levels of warming than the highest emissions pathway (RCP8.5).

RCP8.5: Represents a high-emissions scenario where GHG concentrations continue to increase over the century, reaching about 935 ppm CO_2e by 2100. This scenario is not consistent with the goal of limiting global warming to below 2°C and result in the highest levels of warming among the RCPs.

The IPCC has also developed a set of scenarios, known as Shared Socio-Economic Pathways (SSPs), to understand the potential impacts of different social and economic development pathways on GHG emissions and climate as a basis for its latest report. The SSPs are based on five scenarios representing different assumptions about the future direction of global development, including population growth, economic development, technological change and policy choices. Each SSP is associated with a specific set of GHG emission scenarios, ranging from low to high emission levels linked to RCPs. Rather than predicting the future, SSP scenarios aim to provide a range of possible futures that can be used to explore the potential impacts of different development pathways on climate and other aspects of the environment (Riahi et al., 2017). In the SSP labels presented below, the first number refers to the assumed Common Socio-Economic Route and the second to the radiative forcing expected to be approximately globally effective in 2100. The assumptions of these scenarios can be briefly summarized as follows.

SSP1-1.9 and 2.6: This route, also known as "Sustainable Development", a future of global development characterized by low population growth, rapid technological change and strong efforts to reduce greenhouse gas emissions and adapt the impacts of climate change.

SSP2-4.5: Also known as "Middle of the Road", this route represents a future of global development characterized by moderate population growth, moderate technological change and limited efforts to reduce GHG emissions and adapt to the impacts of climate change, and is associated with the RCP4.5 emissions scenario.

SSP3-7.0: Also known as "Regional Competition", this route represents a future where global development is characterized by high population growth, slow technological change and limited efforts to reduce GHG emissions and adapt the impacts of climate change, and is associated with the RCP6 emissions scenario.

SSP5-8.5: Also known as "Fossil Fuel Development", this route represents a future where global development is characterized by high population growth, slow technological change and limited efforts to reduce GHG emissions and adapt to the impacts of climate change. This pathway is also associated with the RCP8.5 emissions scenario.

3. Climate Models

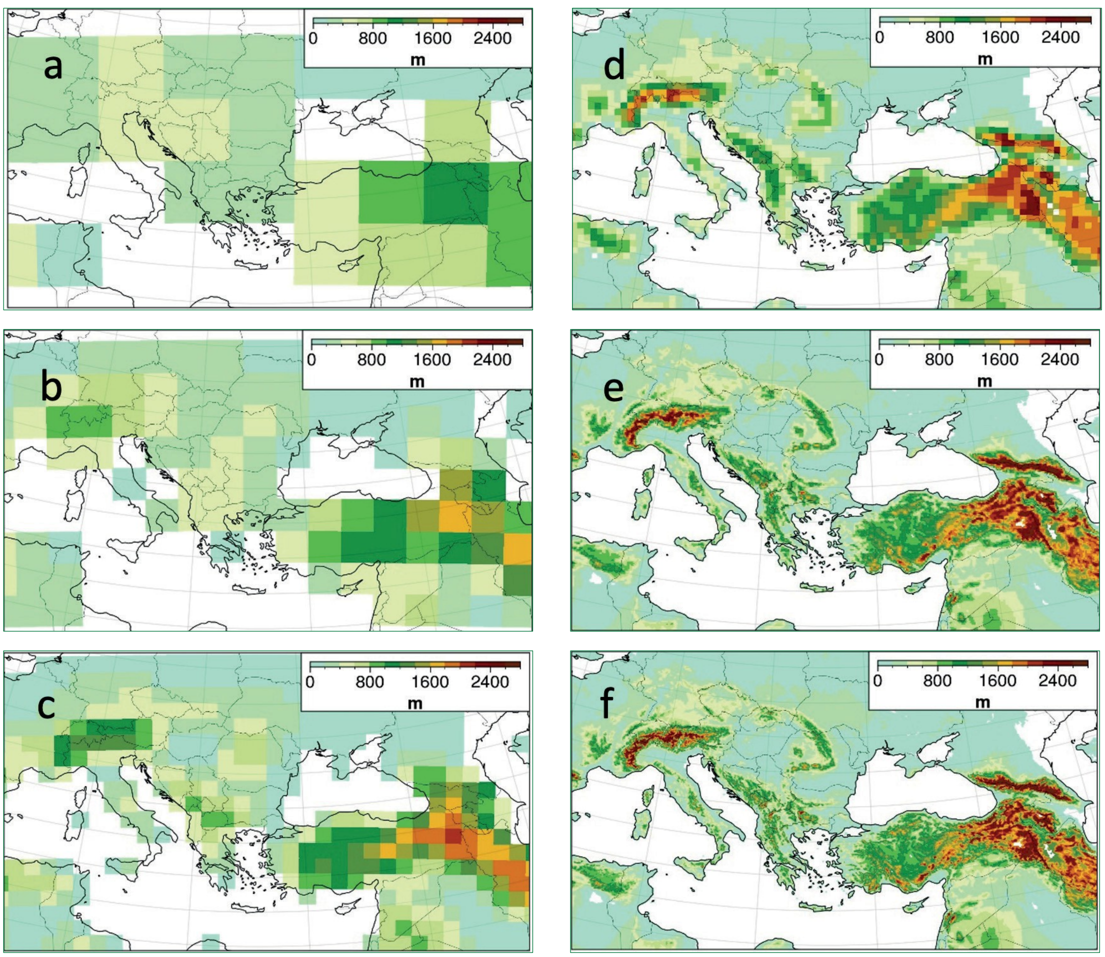
Many climate models have been developed to simulate climate projections due to natural climate forcings, land use changes, changes in anthropogenic emissions of greenhouse gases and aerosols, and to understand the response of the climate system to these forcings. Global and regional models are the tools we use to improve our knowledge of the most important features of the climate system and the causes of climate change.

Due to the complex nature of the climate system, analyses for quantitative prediction of climate change or climate variability rely on the use of three-dimensional numerical earth system models (climate models). In general terms, a climate model is a mathematical representation of the climate system based on physical, biological and chemical principles and be solved numerically due to the non-linearity of the derived equations. As a result, climate models discrete solutions in space and time of average conditions over regions whose size depends on the resolution of the model.

Even the highest resolution climate models are insufficient to represent small-scale processes such as turbulence in the atmosphere and ocean boundary layer, small-scale topographic features of the circulation, thunderstorms, cloud micro-physical processes, etc. Therefore, the influence of physical and dynamical processes that cannot be explicitly accounted for on large-scale movements is incorporated into climate models with the help of empirical relations. Moreover, the detailed behavior of climate system components is still poorly understood and therefore cannot be included in climate models. These approaches are the main source of uncertainty in the predictions of climate models. For this reason, ensemble simulations of climate models developed with different institutions and features and the range of change of the models in the ensemble are used in climate projections.

In addition to the physical, biological and chemical information contained in the model equations, climate models use inputs obtained from observations or other modeling studies. While a climate model that describes almost all components of the climate system requires relatively limited data such as radiation, the radius and rotation period of the earthtopography of land and bathymetry of the oceansome properties of rocks and soil, etc., parts that explicitly account for the physics of the atmosphere, ocean and sea ice require boundary conditions such as the distribution of vegetation, the topography of ice sheetsetc. that are required for all subsystems of climate system componentsOr a boundary condition such as the topography of the ice sheet, which is held constant in some models, as an interactively changing parameter in the model when the aim is to study climate change on a longer time scale. In climate models, changes in $CO_{(2}$concentration according to future emission scenarios are given to the model as a radiative forcingclimate models that calculate the carbon cycle between climate system components

CO_2 concentrations are calculated in parallel with these inputs in the models. The expansion of global atmosphere-ocean observations with satellite technologies, better understanding of the interactions between the components of the climate system, and advances in computer technologies that enable higher resolution calculations are increasing the predictive reliability of climate simulations day by day. Figure 1 shows the change in the resolution of global and regional climate models from the first report of the IPCC to the latest report. While before 1990, climate models exhibited climate simulations based on the coupling of atmosphere and ocean models with a resolution of 500 kmtoday global and regional modeling approaches have evolved to include cycles such as atmosphere, land, ocean, sea ice, aerosols, carbon cycle, vegetation, sulfur and nitrogen. Especially in recent years, climate simulations have started to be performed at scales that allow convection with regional modeling using the outputs of global climate models. Figure 1f shows how precisely the resolution of models at this scale can express topography.



Resolution of climate models ***a****500 km****b****250 km****c****100 km****d****50 km****e****10 km and* ***f****3 km*

Global climate projections are estimates of how the climate is expected to change in the future, based on the best available scientific results. These projections are produced based on how natural and human-induced factors that can affect climate, such as the concentration of greenhouse gases in the atmosphere, changes in the sun's energy, volcanic eruptions, etc., will change the climate. Global climate projections often take into account climate scenarios based on different assumptions about future greenhouse gas emissions and other factors that could affect climate. In recent years, the scenarios discussed in chapter two have been widely used and can be used to understand the potential impacts of climate change on a wide range of variables such as temperature, precipitation, sea level and the frequency and intensity of extreme weather events. These projections are also an important tool for policy and decision makers, as they can help inform the development of strategies to mitigate and adapt to the impacts of climate change. However, it is important to remember that climate projections are based on a number of assumptions and are subject to uncertainty, and that actual climate changes occurring in the future may differ from the projections.

Global climate projections show that the Earth's average surface temperature will continue to rise over the coming decades and centuries as a result of increasing concentrations of greenhouse gases in the atmosphere.

The pace and magnitude of this warming depend on several factors, including the levels of greenhouse gas emissions, the efficiency of natural sinks (such as forests and oceans) in absorbing carbon dioxide, and the sensitivity of the climate system to these emissions.

4. Global Climate Projections

Projections from the Coupled Model Intercomparison Project 6 (CMIP6) using the new scenarios, Common Socio-Economic Pathways, show that temperatures will continue to rise until mid-century under all emissions scenarios (Figure 2). However, without significant reductions in emissions of CO_2 and other greenhouse gases, global average temperatures are unlikely to exceed 2ºC in the 21st century. Even the lowest emission scenario, SSP1, predicts a temperature increase of 1.0-1.8 ºC by the end of the century (2081-2100), while the medium SSP2 and high SSP5 emission scenarios project a temperature increase of 2.1-3.5 ºC and 3.3-5.7 ºC, respectively. Therefore, it seems highly likely that the 2ºC temperature increase will be exceeded in both the medium and high emission scenarios. Increases and decreases in average temperatures are to show an upward and downward trend in decadal time frames.

In the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios, it is very likely that the 1.5°C threshold will be exceeded around 2030 on average, the 2°C threshold will be exceeded around 2043 on average in the SSP5-8.5 scenario and the 3°C threshold will be exceeded around 2062 in the SSP5-8.5 scenario. In the SSP1-1.9 and SSP1-2.6 scenarios, the 2°C threshold is not likely to be exceeded. Exceeding the 4°C threshold would occur by the end of the century in the SSP5-8.5 scenario. The last time the Earth 3 to 4 ºC warmer was 30 million years ago, when the climate was drastically different and the sea level was 20 to 30 meters higher (Schneider et al., 2014).

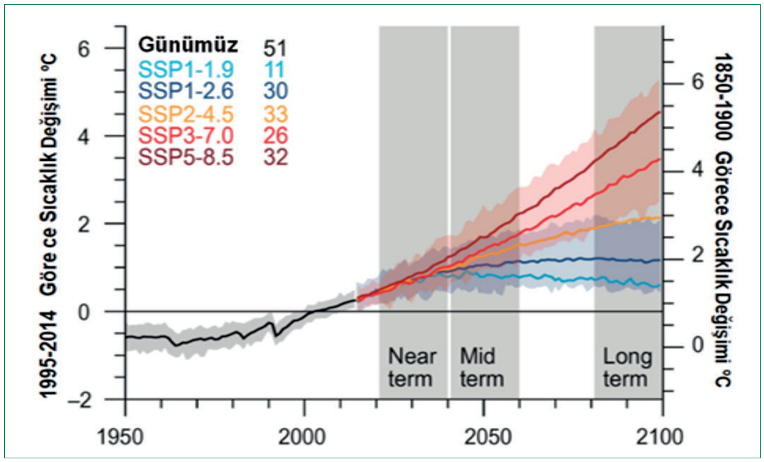


Figure 2. *Change in **a)** temperature and **b)** precipitation in climate simulations for CMIP6 present and future scenarios (IPCC AR6, 2021)*

The CMIP6 models project that the annual average surface air temperature will warm about 50% more on land than in the ocean and about 2.5 times more in the Arctic than the global average. Over the period 2081-2100, the SSP1-1.9 and SSP5-8.5 scenarios show a warming range of 0.3°C-2.0°C and 3.5°C-7.6°C for land temperatures relative to 1995-2014, respectively. The range of change in Arctic surface air temperature is expected to be between 0.5°C-6.6°C and 6.2°C-15.2°C (IPCC, 2021).

It is seen that regional temperature, precipitation and atmospheric circulation characteristics change when global average temperatures are 1.5°C, 2°C, 3°C and 4°C compared to the 1850-1900 period. The responses of different regions of the world to average warming show differences.

For example, at an average temperature increase of 1.5°C, temperature increases in ocean areas remain in the range of 0-1.5°C, while the temperature increase between 4-5°C, especially in the north polar regions. The largest increase in annual average temperature is found in the upper latitudes of the northern hemisphere at all levels of global warming (IPCC, 2021).

Reduced ice cover in the polar regions reduces the surface albedo, more solar radiation to be absorbed, while strong warming in the narrow polar region increases poleward heat transfer by the atmosphere and oceans, in much higher than average increases in temperatures. CMIP6 ensemble averages show that for global warming of 1.5°C, 2°C, 3°C and 4°C, Arctic annual mean temperatures warm by multiples of the global average of 2.3, 2.5, 2.4 and 2.4, respectively. That is, Arctic warming varies linearly with global average warming. The Antarctic continent in the southern hemisphere is expected to warm at a higher rate than mid-latitude ocean areas in the same hemisphere at all levels of global warming. In the 21st century, the southern hemisphere warming at high latitudes is to exceed the change in the global average temperature, or to be significantly greater than warming in the tropics for temperature changes ranging between 1.5°C and 4°C. In sum, while the global average temperature is expected to increase, the magnitude and pattern of temperature change will vary across different regions and seasons, with some regions experiencing more or less warming than the global average.

While global average precipitation increases by 1-3% for every 1°C as global average temperatures rise, precipitation change patterns do not change linearly with temperature increase. However, most of the models under CMIP6 agree on the expected precipitation change, although they differ across scenarios. Precipitation is likely to increase at high latitudes and in the tropics, and possibly in much of the monsoon region. However, in all scenarios, precipitation will decrease in the Mediterranean, South Africa, Australia and the subtropical latitudes of South America. The amounts of increase and decrease in precipitation will be exacerbated at higher levels of global warming. Overall, statistically significant changes in regional annual average precipitation are expected when global average temperatures increase by 2.5°C-3°C or (Tebaldi et al., 2015). The general conclusion of almost all models is that average warming will be higher over land. As warming increases, the regions of statistically significant increases or decreases in precipitation will expand, both globally and over land areas (Pendergrass et al., 2017).

In simulations where the global average temperature exceeds 1.5°C relative to the pre-industrial revolution, the average change in precipitation over land when exceeding the threshold temperature relative to the period 1850-1900 is around 1.6%. For scenarios with common global warming above 2.0°C (SSP3-7.0 or SSP5-8.5) and 3.0°C (SSP5-8.5), the average increase in precipitation over land when global temperatures exceed 2.0°C and 3.0°C is about 2.6% and 4.9%, respectively. Under SSP1-1.9 and SSP1-2.6, on average, the global land precipitation change for simulations with global warming exceeding 1.5°C and 2.0°C would be about 1.9% and 3.0%, respectively.

According to IPPC, global climate projections that precipitation will increase in high latitudes (near the poles) and some tropical regions and decrease in some subtropical and mid-latitude regions. Overall, these projections indicate that the intensity and frequency of extreme precipitation events (such as extreme rainfall or snowfall) will increase in many regions.

Regional extreme changes climate change are expected to vary parts of the world. Current scientific publications on the impacts of climate change on extreme precipitation indicate that the intensity and frequency of events are to increase. Many parts of Europe are expected to experience an increase in the frequency and intensity of extreme precipitation events, with the largest increases occurring in the northern and western parts of the continent. These changes are likely be accompanied by an increase in the frequency and intensity of floods and landslides. Many parts of North America are likely to experience an increase in the frequency and intensity of extreme precipitation events, with the largest increases occurring in the Northeast and Midwest. parts of Asia, especially the monsoon regions will increase in the frequency and intensity of extreme precipitation events, with the largest increases occurring in the summer months. While the Middle East is likely to experience an increase in the frequency and intensity of extreme precipitation events, as the region becomes hotter and drier, an increase in the intensity and frequency of drought is expected, especially in summer.

Global mean sea level is expected to rise as a result of ocean thermal expansion and glacial melt, consistent with changes in global surface temperature. Today, sea level rise in the last decade has been greater than in previous decades and has been around 3.7 mm/year since the 1960s.

Sea level responds more slowly to greenhouse gas emissions than global surface temperature. However, even after emissions cease, heat storage in the oceans and changes in deep ocean circulation can cause sea level changes on a timescale of centuries or millennia. For example, in the lowest emission scenario, the increase in the heat capacity of the oceans is projected to continue until 2300. By 2100, sea level is projected to rise by 0.28-0.55 m in the SSP1-1.9 scenario and by 0.63-1.01 m in the SSP5-8.5 scenario compared to the 1995-2014 average.

5. Turkey Projections

Studies show that the Mediterranean basin, including Turkey, is one of the climate change hotspots where the effects of global warming are seen as a result of changes in greenhouse gas concentrations in the atmosphere (Diffenbaugh & Giorgi, 2012). CMIP5, CMIP6, HighResMIP and CORDEX simulations all project that temperatures in the Mediterranean basin will increase between 3.5°C and 8.75°C for the RCP8.5 scenario by the end of the century. Largely of models and emission scenarios, summer warming is projected to be up to 40-50% higher than global annual warming. The projected warming over Turkey, the Balkans, the Iberian Peninsula and North Africa can reach twice the global average locally, and in summer temperatures increases the amplitude of the annual temperature oscillation (Lionello & Scarascia2018Almazroui et al.2020). Climate predict a decrease in precipitation in all seasons and an expansion of the Mediterranean climate northwards and eastwards, with affected regions becoming more arid with increasing drought (Alessandri et al.2015Rajczak & Schär, 2017; Lionello & Scarascia, 2018Spinoni et al.2020). As a result of the decrease in precipitation, the decrease in soil moisture and thus the inability to cool the surface through evaporation will lead to a faster increase in temperatures in the region.

Determining global climate projections at a higher resolution in a region with highly variable topography, coastal zones and vegetation cover such as Turkey's geography is important in determining strategies for adaptation studies and measures to be taken. Climate change will have significant impacts on sectors such as agriculture, water resources, health and tourism.

can create. To provide information at better resolution, global climate model outputs are transferred to limited areas using dynamic downscaling with regional climate models. Many modeling studies have been conducted to investigate climate variability in Turkey. Ünal et al. (2001); Önol and Semazzi (2009); Ünal et al. (2010); Bozkurt and Şen (2011); Önol (2012); Önol and Ünal (2014), Önol et al. (2014), MGM (2015) and SYGM (2016) are examples of climate modeling studies involving Turkey. However, in recent years, regional climate simulations at 3 km resolution have started to be carried out over Turkey in order to conduct impact studies at local scale (Yürük, 2017; Ünal & Yürük, 2017; Yürük & Ünal, 2016; Yürük et al., 2022). A major source of uncertainty in regional climate model simulations stems from the parameterization of sub-grid scale convection. As the scales that allow convection are approached with increasing model resolution, it is possible to turn off convection parameterization. Simulations at very high resolutions are particularly capable of better representing the statistics associated with extreme weather events (e.g. extreme precipitation).

SGYM (2016) performed future climate projections for the RCP4.5 and RCP8.5 scenarios at 10 km resolution over Turkey using the RegCM regional model forced with initial and boundary conditions defined by MPI-ESM-MR and CNRM-CM5.1, HadGEM2-ES earth system models selected from the CMIP5 database. The projections of these models predict that average temperatures will increase by 2.0°C, 2.5°C, and 3.4°C in the last decade of the 21st century compared to the 1970-2000 reference temperatures for the medium emission scenario RCP4.5, and by 4.5°C, 4.3°C, and 5.9°C in the RCP8.5 scenario, respectively. In the RCP4.5 scenario, the differences between winter and summer seasons in temperature increases reach 1.3°C at most, while in the RCP8.5 scenario, summer and winter temperature trends show significant differences and reach 2.7°C. As for precipitation, Turkey's average precipitation decreases in both scenarios. RCP8.5 indicates that Turkey will be exposed to a stronger drought towards the end of the century compared to the medium scenario. However, the spatial distribution of seasonal and annual precipitation changes is similar in all models.

Figure 3.a shows the temperature simulation results for RCP8.5 of the COSMO-CLM regional model with a resolution of about 0.11 degrees (12 km) forced by the MPI-ESM-LR earth system model. In general, temperature increases are about 1.5-2°C after 2030s, 3°C in the north and 3.5-4.0°C in the southeast after 2050, and about 4°C on average after 2070, but 5.5-6.0°C in the southeast region of Turkey.

Figure 3.b shows the percentage change in precipitation compared to the reference period. Our country the most precipitation in winter and spring seasons. Precipitation deficiencies in the winter and spring seasons in the southern latitudes of Turkey will intensify towards the end of the century, which will significantly affect our water resources and agricultural activities in these regions. In the future, the climate regime in the northern regions of Turkey is projected to be similar or slightly wetter than the reference period. However, in the period 2076-2100, the lack of precipitation in the Mediterranean, South Aegean, South Eastern and Eastern Anatolia regions will become very severe,

will decrease by around 30-35% compared to the reference period precipitation. When the precipitation changes are analyzed on the basis of basins, it is seen that the highest changes are in the Eastern Mediterranean, Western Mediterranean and Ceyhan basins in the direction of decrease. Especially the regions with high elevation are the regions where snowfall is frequent and snow cover remains until spring months without melting. However, increasing temperatures change the character of winter precipitation from snow to rain, reducing the capacity of natural water storage reservoirs on the surface, and the ability of the surface to reflect solar radiation decreases with the early melting of the snow cover. This to accelerated temperatures in these regions as more incoming solar radiation is absorbed.

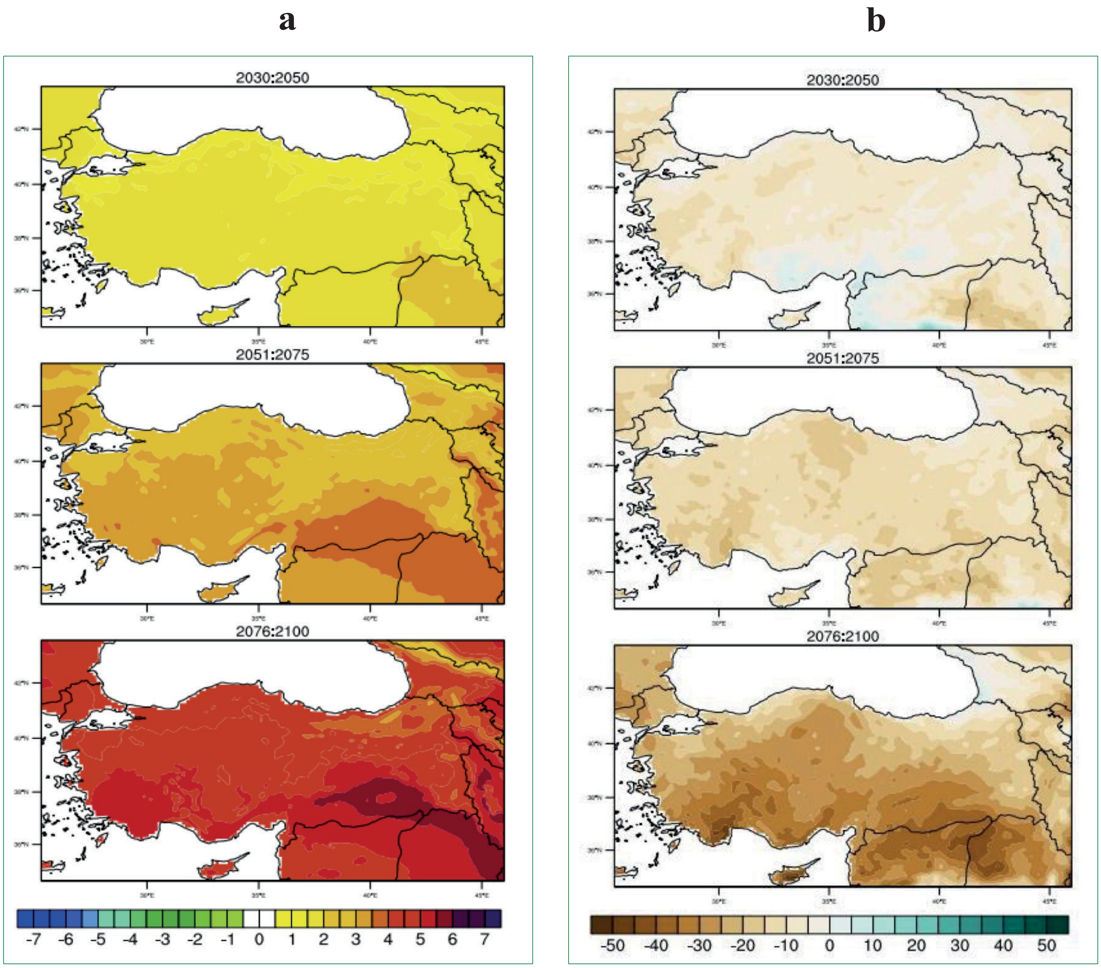


Figure 3. *For the RCP8.5 scenario,* ***a)*** *change in temperatures,* ***b)*** *change in precipitation in % for the future periods 2030-2050, 2051-2075, 2076-2100 compared to the average reference period 1989-2005.*

Therefore, in regions covered with snow for longer periods of time, increasing greenhouse gas forcings, especially towards the second half of the century, lead to more rapid temperature increases. In addition, even if there is no change in precipitation amounts, it should be expected that runoff will increase in winter and decrease in spring due to increasing temperatures.

This is because rising temperatures will cause less snowfall and accumulation in winter and earlier melting of existing snow in spring, altering surface runoff. In addition, increased evaporation at higher temperatures will create water stress in spring and summer.

Changes in the 12-month Standard Precipitation Index (SPI) and Standard Precipitation Evapotranspiration Index (SPEIaverages over Turkey were calculated for the period 2030-2100 (Figure 4). While the difference between SPI and SPEI is quite small in the calculations for the reference period, the difference gradually widens between 2030-2100. SPI refers to drought based on precipitation only. The decrease in precipitation across Turkey towards the end of the century will exacerbate drought and extend the duration of dry periods. However, in general, higher temperatures increase evapotranspiration, the soil of moisture, exacerbating drought and causing it to prevail for longer years.

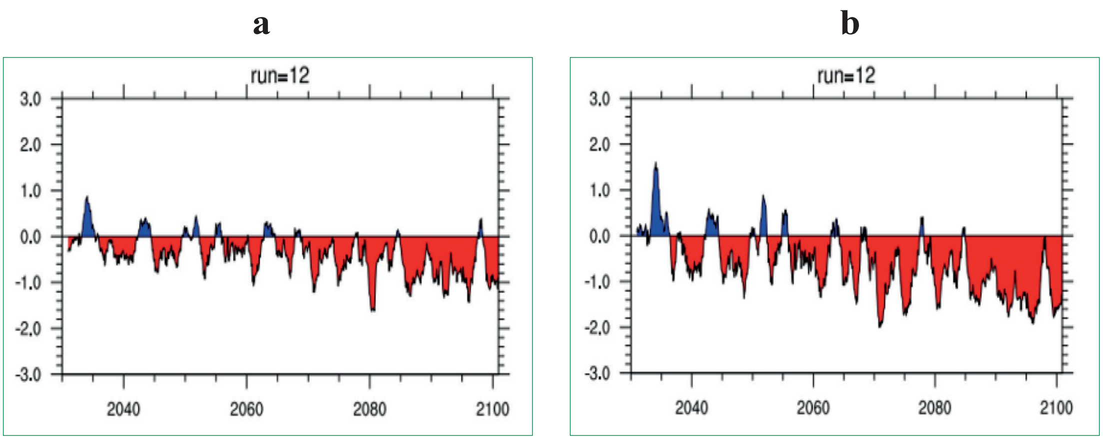


Figure 4. *12-month drought indices change for RCP8.5 scenario **a)** SPI and **b)** SPEI*

6. Results

It is widely accepted by scientists that global climate change over the last century is a result of human impacts and changes in the composition of the atmosphere (IPCC, 2007; IPCC, 2013; IPCC, 2021). The exponential increases in greenhouse gases in the atmosphere and the acceleration of this increase in the last few decades have brought studies to the forefront determine how the components of the climate system will respond to these changes.

Projections for the new SSP scenarios show that temperatures continue to rise until mid-century under all emission scenarios. Without a significant reduction in greenhouse gas emissions and removal of carbon from the atmosphere through geoengineering approaches, global average temperatures are likely to exceed 2ºC in the 21st century.

likely. Even the lowest emission scenario predicts a temperature increase in the last two decades of the century in the range of 1.0-1.8 ºC, while the high emission scenarios predict a range of 3.3-5.7 ºC respectively. Therefore, it seems highly likely that the 2ºC temperature increase will be exceeded in both the medium and high emission scenarios. In addition, the polar regions are warming at a faster rate than the tropics, reducing the temperature contrast between the equator and the poles and altering both the atmosphere and ocean circulation. Accordingly, precipitation patterns and the amount of precipitation (including rain, snow and other forms of precipitation) are expected to show regional and seasonal variations as the climate warms, indicating both increases and decreases in precipitation. Some regions will see more or less precipitation than the global average. In summary, the CMIP6 models assess that there is high confidence that global average precipitation will increase due to the accelerating hydrological cycle combined with an increase in global average surface temperature. Precipitation is likely to increase at high latitudes and in the tropics, possibly over large parts of the monsoon region, but possibly decreasing in subtropical regions. Increases and decreases in precipitation are with high confidence to grow at higher levels of global warming.

Turkey is located in the Mediterranean basin, which is defined as the most vulnerable to climate change. Regional modeling studies have that average temperatures will increase until the end of the century according to the RCP4.5 and RCP8.5 scenarios, and by the end of the century, temperature increases will be in the range of 2℃ to 6℃ depending on the scenarios. Simulations that temperatures warm much more in summer than in winter, with stronger temperature increases in the South Aegean coast, Mediterranean and South East Anatolia regions. The increase in daytime and nighttime temperatures will increase both the frequency and duration of heat waves in Turkey. Considering the increase in atmospheric humidity, sensible temperatures will be higher. Accordingly, increases in energy use for cooling purposes should be expected in the summer months.

Both the optimistic and pessimistic scenarios project a decrease in total annual precipitation in Turkey. RCP8.5 indicates that Turkey will experience a stronger drought towards the end of the century compared to the medium scenario. Reduced snowpack in the Eastern Anatolia region could lead to significant reductions in river flows in spring and summer, when melting occurs today. This will cause economic losses in Turkey's agriculture and energy sectors. Increased evapotranspiration, especially due to the increase in temperatures, will increase the need for irrigation in the agricultural sector.

7. Sources / References

Alessandri, A., De Felice, M., Zeng, N., Mariotti A., Pan Y., Cherchi A., Lee J. Y., Wang B., Ha K. J., Ruri P., Artale V. (2015), Robust assessment of the expansion and retreat of Mediterranean climate in the 21stcentury. *Scientific Reports*, 4(1), 7211.

Almazroui, M., Saeed, F., Saeed, S., Islam M. N., Ismail M., Klutse N., Siddiqui M. H. (2020), Projected Change in Temperature and Precipitation Over Africa from CMIP6. *Earth Systems and Environment*, 4(3), 455-475

Alessandri, A., De Felice, M., Zeng, N. Robust assessment of the expansion and retreat of Mediterranean climate in the 21[st] century. *Sci Rep* **4**, 7211 (2014). https://doi.org/10.1038/srep07211

Bozkurt, D., & Sen, O. (2011). Precipitation in the Anatolian Peninsula: sensitivity to increased SSTs in the surrounding seas. *Climate Dynamics*, 36(3-4), 711-726.f

Diffenbaugh & Giorgi, (2012), Climate change hotspots in the CMIP5 global climate model ensemble, *Climatic Change*, 114(3-4), 813-822.

IPCC (2001). Climate change 2001: impacts adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. McCarthy, J. J., Canziani, O. F., Leary, N. A., D. J. Dokken, & K. S. White (Eds.). Cambridge: Cambridge University Press.

IPCC (2007). Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, H. L. Miller Jr., & Z. Chen (Eds.). Cambridge: Cambridge University Press.

IPCC (2013). Climate Change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of Intergovernmental Panel on Climate Change. Panel. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp

IPCC. (2021). Climate Change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson- Delmotte, V., P. Zhai, A. Pirani, SL Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, MI Gomis, M. Huang, K. Leitzell, E. Lonnoy, JBR Matthews, TK Maycock, T. Waterfield, O. Yelekci, R. Yu, and B. Zhou (eds.). Cambridge University Press

IPCC SREX. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.

Lionello and Scarascia, (2018) The relation between climate change in the Mediterranean region and global warming. *Reg Environ Change*, 18, 1481-1493.

MGM, (2014) Climate Change Projections for Turkey with New Scenarios, General Directorate of MeteorologyAnkara.

Pendergrass, A.G., R. Knutti, F. Lehner, C. Deser, and B.M. Sanderson, 2017: Precipitation variability increases in a warmer climate. *Scientific Reports*, 7(1), 17966.

Rajczak, J. & C. Schär, (2017) Projections of Future Precipitation Extremes Over Europe: A Multimodel Assessment of Climate Simulations. *Journal of Geophysical Research: Atmospheres*, 122(20), 10773-10800.

Riahi, K., van Vuuren D. P., Kriegler E., Edmonds J., O'Neill B. C., Fujimori S., Bauer N., Calvin K., Dellink R., Fricko O., Lutz W., Popp A., Cuaresma J. C., KC S., Leimbach M., Jiang L., Kram T., Rao S., Emmerling J., ..., Tavoni M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change,* 42, 153-168

Schneider S.H., (2014) Climate Change Science and Policy, Island Press, 2014. ProQuest Ebook Central.

Spinoni, J., Barbosa, P., Bucchignani, E., Cassano, J., Cavazos, T., Christensen, O. B., Christensen, J. H., Coppola E., Evans J., Geyer B., Giorgi F., Hadjinicolaou P, Jacob D., Katzfrey J., Koenigk T., Laprise R., Lennard C. J., Kurnak L., Li D., ..., Dosio A. (2020) Future Global Meteorological Drought Hot Spots:A Study Based on CORDEX Data. *Journal of Climate*, 33(9), 3635-3661.

Önol, B. (2012). Effects of Coastal Topography on Climate: High-Resolution Simulation with a Regional Climate Model. Climate Research.

Önol, B., Semazzi, F. (2009). Regionalization Of Climate Change Simulations over the Eastern Mediterranean. J.Climate, 1944-1961.

Önol, B.; Semazzi, F.H.M.; Unal, Y.; Dalfes, H.N. (2006) Regional Climatic Impacts of Global Warming over the Eastern Mediterranean. Climate Change and the Middle East - Past, Present and Future.

Önal, B., & Ünal, Y. (2003). Climate Simulation of Turkey and Its Neighborhood by Regional Climate Model:Sensitivity of Surface Conditions. Nice.

Önol, B., & Unal, Y. (2014). Assessment of climate change simulations over climate zones of Turkey. *Regional Environmental Change,* 14, 1921-1935.

Ünal, Y. S., Karaca, M., & Dalfes, N. (2000) Regional Climate Change due to the Southeastern Anatolian Project in Turkey', International Meeting on 'Detection and Modeling of Recent Climate Change and its Effects on a Regional Scale.

Ünal, Y.S.; Önol, B.; Karaca, M.; Dalfes N., (2001). Climate of GAP Basins in the 21st Century: Simulations with a Medium Scale Model. ITU Research Fund Project.

Ünal, Y.S.; Önol, B.; Menteş.S.; Borhan, Y.; Kahraman, A.; Ural, D. (2010) Investigation of the Effects of Global Climate Change on Turkey with Regional Climate Model.

Ünal, Y., Önol, B., Menteş, S., Borhan, Y., Kahraman, A., & Ural, D. (2010). Investigation of the Effects of Global Climate Change on Turkey with Regional Climate Model. TUJJB-TUMEHAP-02-06, 2006-2010. Turkish National Union of Geodesy and Geophysics.

Ünal, Y., & Yürük, C. (2017). Changes in Precipitation extremes in High Resolution Simulations of COSMO-CLM driven by MPI-ESM-LR under RCP8.5 scenario.

Van Vuuren, et al. (2011) The representative concentration pathways: an overview. *Clim. Change*, 109, 5-31.

Yürük, C. (2016). COSMO-CLM (CCLM) climate simulations over Turkey: Performance evaluation and climate projections for the 21st century. (Master thesis). Istanbul Technical University, Graduate School of Science, Istanbul.

Yürük, C., & Ünal, Y. (2016). Changes in Temperature extremes in High Resolution Simulatıons of COSMO-CLM driven by MPI-ESM-LR under RCP8.5 scenario over Western Turkey. MedVLIVAR 2016 Conference. Athens.

Yürük, C., & Ünal, Y. (2017). Performance Evaluation of COSMO-CLM (CCLM) over Istanbul. COSMO/CLM/ICON/ART User Seminar. Offenbach.

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