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Climate Change Training Module Series 1

# SCIENTIFIC BASIS OF CLIMATE CHANGE AND IMPACTS ON TURKEY

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# SCIENTIFIC BASIS OF CLIMATE CHANGE AND IMPACTS ON TURKEY

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The original content of this publication has been prepared in Turkish.
In case of discrepancies with the English translation, the Turkish version is valid.

# SCIENTIFIC BASIS OF CLIMATE CHANGE AND IMPACTS ON TURKEY

## CONTENT

## ABBREVIATIONS

| | |
|---|---|
| δD | Deuterium |
| $\delta^{18}O$ | Oxygen 18 Isotope |
| AHP | Analytic Hierarchy Process |
| AO | Arctic Oscillation |
| Cb | Cumulonimbus |
| CDR | Carbondioxide Removal |
| CFC | Chlorofluorocarbons |
| $CH_4$ | Methane |
| $CO_2$ | Carbondioxide |
| DDSLR | Dry Days Since Last Rain |
| E | Eccentricity |
| ENSO | El Niño – Southern Oscillation |
| TMS | Turkish Meteorological Service |
| $H_2O$ | Water Vapour |
| HFC | Hydrofluorocarbons |
| ICTP | International Centre for Theoretical Physics |
| IPCC | Intergovernmental Panel on Climate Change |
| ISR | Incoming Short-wave Radiation |
| ISWSR | Incoming Short-wave Solar Radiation |
| LWR | Long-wave Radiation |
| NH | Northern Hemisphere |
| M-K | Mann-Kendall |
| MCI | Mediterranean Climate Index |
| $N_2O$ | Nitrous oxide |
| NAO | North Atlantic Oscillation |
| $O_3$ | Ozone |
| OLR | Outgoing Longwave Radiation |
| OLWGR | Outgoing Long-wave Terrestrial Radiation |
| P | Precession |
| PFC | Perfluorocarbons |
| RCP | Representative Concentration Pathway |
| SWR | Short-wave Radiation |
| T | Tilt |
| $T_{min}$ | Minimum Air Temperature |
| USA | United States of America |
| WMO | World Meteorological Organization |

## EXECUTIVE SUMMARY

Global climate has experienced significant variations and changes in all spatial and temporal scales from the formation of Earth, which is around 4.6 billion years old, up to now. At all times since Earth's formation, significant changes have taken place on the physical geography of the Anatolia (landscapes, weather and climate, soil and vegetation, surface and underground waters, rivers and lakes, glaciers, ecosystem[1], biome and biodiversity, etc.).

Global climate is a highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions amongst them. In short, it is also called the climate system. In this scope, the external forcings and factors that cause changes in natural variability of climate include: natural events such as changes that interact with the sub-systems of climate system and are affected from them - for example movement of Earth's rigid tectonic plates and volcanic eruptions, solar activity changes, changes in astronomical relations[2] between Earth and Sun and as well as anthropogenic changes in the composition of atmosphere with the industrial revolution (human factors such as use of fossil fuel, destruction of forests etc.). In other words, climatic changes formed by external forcing and factors occur under the control and the impact of natural events that are outside of the climate system and anthropogenic forcing and factors. The astronomical relationships involve a series of periodical changes called Milankovitch cycles and could provide significant evidence in explaining long-term fluctuations in climate.

The most important result of the enhanced greenhouse effect which has become stronger as a result of gradual increase of the concentration of greenhouse gases in the atmosphere after the industrial revolution due to human activities is formation of an additional positive radiative forcing on the energy balance of the Earth, making the planet's climate warmer and more variable. On the other hand, both at the global scale and regional scale, climate change causes important variations in the frequency, magnitude, spatial distribution, duration, and timing of extreme weather and climate events. For example, a significant decrease and increase trend have been observed in the precipitation in various regions of the world during 1950 – 2011, which are known by their high variability both in spatial and temporal aspects. Besides, increases have been observed in precipitation events in various regions of the world and Turkey, and certain extreme events resulted in important changes.

According to the latest findings that rely on analysis of long term climatologic observations, changes in extreme weather and climate events increased in Turkey, which were observed as significant increase in the number of summer and tropical-days in particular after 1990s, and significant increase in frost days and snowy days, and the elongation in the frost-free period of the year. Whereas around 50% of the records in Turkey related to maximum air temperature have occurred since 2000, this rate decreased down to 10% in records related to minimum temperatures vales. In other words, in the last 25-year period in Turkey, the temperature regime has significantly changed towards temperate and warmer conditions, and there occurred significant changes in the frequency and magnitude of heatwaves.

[1] It is a system wherein the living organisms interact with themselves and their physical environment.

[2] Interactions of Earth with the Sun namely Earth's axial tilt (T), the eccentricity (E) of the Earth's orbit around the Sun (eccentricity, E) and the precession movements during its rotation around the Sun and around its own axis (P).

In addition to the observed changes and trends, climate model simulations indicate an increase in the frequency and/or magnitude of extreme weather and climate events in many parts of the World in 21st century in connection with the increasing lower troposphere and surface air temperatures in general, and the increasing thermal energy (positive radiative forcing) and accelerated and/or strengthened hydrological cycle.

The first objective of this module could be summarized as to discuss the conceptual and theoretical aspects of climate change and its scope and causes of, and to ensure that the climate change phenomenon is set within a scientific framework (physical science basis of climate change).

Its second objective is to make an extended (with a broader perspective) and multidisciplinary scientific synthesis of climate change and variability in the future based on observed climate change in the World and Turkey and climate model projections executed that are relying on various greenhouse gas emission scenarios, and numerous published peer-reviewed articles and papers and the special analysis and assessments particularly carried out for this study.

# 1. INTRODUCTION

It is beneficial to start the introduction section by defining important concepts related to the issue. One of these, namely climate change, could be defined as "*statistically significant variation in the mean state of the climate or of its variability, persisting for decades or longer years*" (Türkeş, 2008a and 2008b). Climate variability, which is the second important concept, could be defined as "*variations that occur in the mean state of climate and other statistics such as standard deviation and the frequency of extreme events, and their probabilities on all temporal and spatial scales*" (ibid). Climate change and variability could occur depending on the natural internal processes interior to the climate system or alterations originate from humans (anthropogenic) and external forcing factors.

Global climate is a highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions amongst them. In short, it is also called the climate system (Türkeş, 2010). External forcings and factors are the changes that are engaged with and affected by the sub-systems of the climate system. For example, it includes natural events such as volcanic eruptions, changes in Sun activities and changes in astronomical relations between Earth and Sun, and the anthropogenic changes in the composition of the atmosphere (Türkeş, 2012a and 2013a). Greenhouse gases and aerosols, which are emitted to the atmosphere as a result of human activities, are the main external forcing and factors that could lead to climate changes, with variable extends of impact.

The potential "external" causes for climate change include movement of Earth's rigid tectonic plates, Sun activities, and alterations in the astronomical relations between Earth and Sun. In other words, climatic changes formed by external forcing and factors occur under the control and the impact of natural events that are outside of the climate system and anthropogenic forcing and factors. The astronomical relationships involve a series of periodical changes called Milankovitch cycles and could provide significant evidence in explaining long-term fluctuations in climate (Erlat, 2010; Türkeş, 2013a).

# 2. GLOBAL CLIMATE CHANGES AND THEIR CAUSES

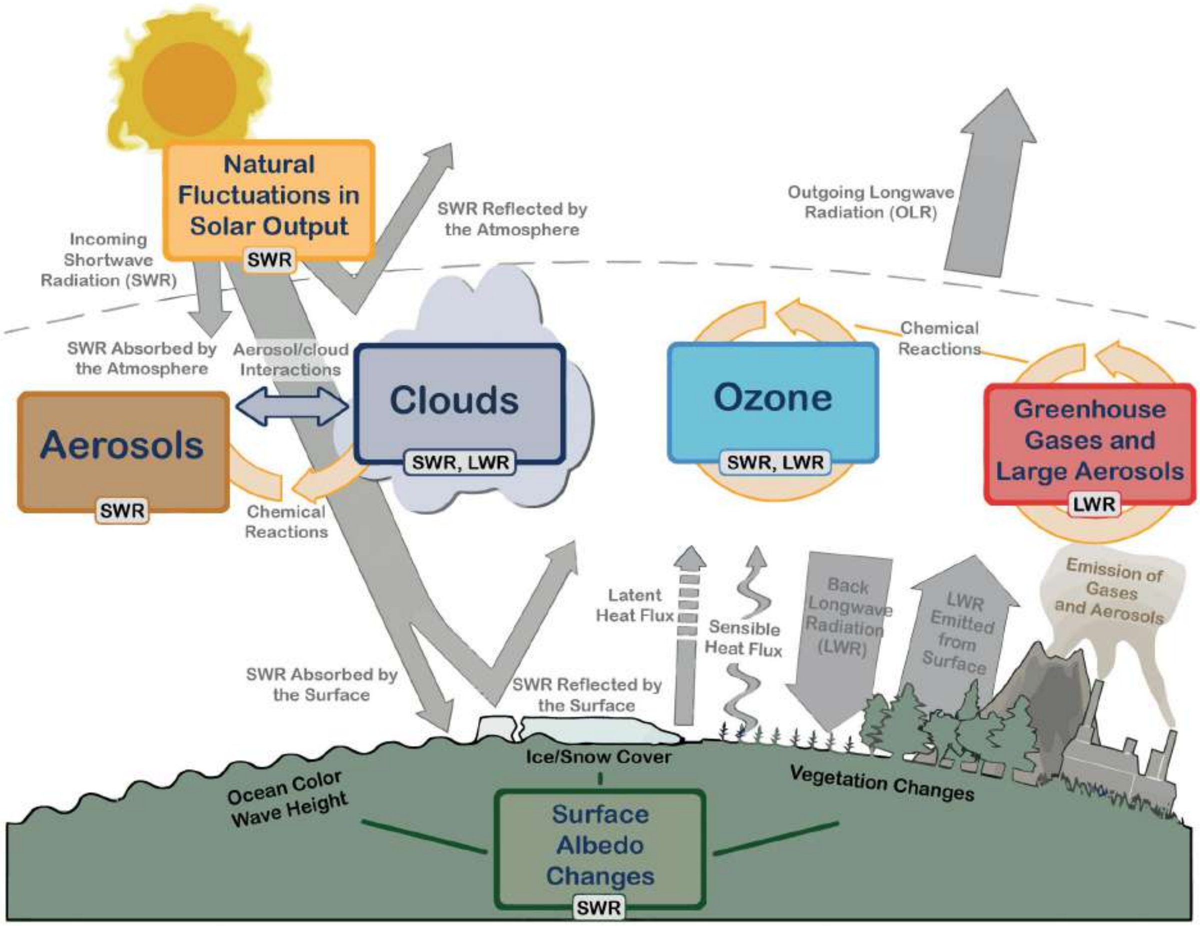
## 2.1. Main Drivers of Climate Change

Main greenhouse gases of which having variable concentration in the atmosphere, are affected from various human activity and responsible from the functioning of natural greenhouse effect mechanism, are carbondioxide ($CO_2$), water vapour ($H_2O$), nitrous oxide ($N_2O$), methane ($CH_4$) and ozone ($O_3$) and artificial products of chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and their various derivatives. Figure 1 demonstrates a diagrammatic synthesis of main drivers and causes of climate change with a very wide perspective from short-wave radiation (SWR) that reaches the upper boundaries of atmosphere from the Sun (incoming, I), and long-wave radiation (LWR) released from the Earth (outgoing, O) to interaction of aerosols, clouds, ozone layer, greenhouse gases and large aerosols with the climate system and their radiative forcings, and from energy fluxes on the Earth and in the atmosphere to albedo[3] and vegetation changes on the Earth's surface.

The radiative balance between incoming short-wave Solar radiation[4] (ISWSR) and outgoing long-wave terrestrial radiation (OLWGR) is affected by various climate drivers on a global scale. Natural oscillations in solar flux outputs (Solar cycles) can cause changes in the Earth's energy balance through oscillations in the value or magnitude ISWSR. Human factors such as the burning of fossil fuels, industrial processes, land-use changes and deforestation, etc. alter the gas and aerosol emissions connected with chemical reactions in the atmosphere, which result in changes in gases and aerosol amounts[5]. $O_3$ (Ozone) and aerosol particles in the atmosphere change the energy balance by absorbing, scattering and reflecting the ISWSR. Some aerosol types may act as cloud condensation nuclei, altering or disrupting the properties of cloud (water) droplets, possibly affecting the formation and characteristics of precipitation (Figure 1). Since the interactions of clouds with SWR and LWR are effective or strong, even small changes in cloud properties can have significant consequences for the radiative or energy budget of the climate system.

[3] It is the fraction of reflected incoming shortwave Sun radiation by the objects.
[4] In general, it is the transfer of heat energy by means of electromagnetic waves.
[5] Volatile substances in the atmosphere or suspended particles in the air (for example, sulphate aerosols etc.)

***Figure 1:*** *Diagrammatic presentation of the main drivers of climate change (Cubasch et al., 2013)*




Anthropogenic changes in greenhouse gases (e.g.$CO_2$, $CH_4$, $N_2O$, $O_3$, CFCs) and large aerosols (> 2.5 μm) in the atmosphere change the amount or intensity of OLWGR by absorbing and re-emitting less energy at lower air temperature alter the OLW radiation. The albedo of the Earth's surface may change due to land cover and vegetation, snow or ice cover, and changes and distortions in ocean colour. All these changes are directed and/or controlled by natural seasonal and daily changes (e.g., Snow cover) and human impact and activities (e.g., Land use changes, change of vegetation formations and their types, etc.).

## 2.2. Natural Causes of Climate Change

To the best of our knowledge, the global climate has tended to have significant variations and changes in all spatial and temporal scales during its 4.6 billion-years long geological history (Türkeş, 2013a). Over millions of years, the climate fluctuated from very warm conditions characterized by surface temperatures above 10 °C in Polar Regions to glacial periods or ages where the inlandsis[6] (ice sheets or continental glaciers) covered most of the mid-latitude continents (See Figure 4). According to some assumptions, the entire

[6] In particular the ice sheets or continent glaciers that cover the polar and polar perimeter regions of the Earth.

surface of the Earth was covered with ice during some past cold periods (Snowball Earth Hypothesis). The lower amplitude fluctuations, which are close to recent times of Palaeozoic time spectrum (545 million years long period), in the last 10.000 years –during the Holocene Epoch, are observed at interannual and decadal timescales, no single year is the same as to a previous one (Erlat, 2010; IPCC, 2013; Türkeş, 2010, 2012a and 2013b).

In connection with its own evolution, the total Solar radiation energy which the Sun emits at all wavelengths from its photosphere layer, at average Sun-Earth distance, and which reaches at unit time to a unit area that is perpendicular to solar waves at the outer limit of the atmosphere (total Solar irradiance or Solar constant, W/m2), has increased by around 30% during the 4.6 billion-year history of the Earth. Variations in total solar irradiance at shorter timescales generally have a similar amplitude. Low-frequency changes in the characteristics of the Earth orbit alter the amount of solar energy received in a particular season on every point on the Earth's surface. The most important fluctuations in this context are observed in the range of 10,000 - 100,000 years. Individual volcanic eruptions produce a general cooling during the first years following the eruption (Erlat and Türkeş, 2015a). Besides, volcanic activities can be responsible for a low-frequency forcing if large eruptions are grouped in a particular decade or century (Figure 1). At longer time scales, the volcanic activities that increase with large scale mountain formation areas (e.g., the Andes in South America) and island arcs (e.g., the Andes in South America), respectively, resulting from the collision of an oceanic plate and a continental plate and / or two oceanic plates, due to the plate tectonics, can lead to a strong cooling tendency that can last for long time period from thousands to millions of years (Türkeş, 2010).

In this context, teleconnection patterns or atmospheric oscillations such as El Niño - Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) or Arctic Oscillation (AO) are important examples of the atmospheric internal forcing of the global climate system (Şahin et al., 2015; Türkeş, 1998, 2000; Türkeş and Erlat, 2003, 2006, 2008 and 2009). Secondly, due to the large inertia of the ocean and inlandsis, the dominant effect of a perturbation[7] can be related to the combination or integration of the forcing over long time scales while higher frequency changes are suppressed. Inertia can also induce a delayed response to a perturbation. Furthermore, the response of the system may involve complex mechanisms leading to large differences between the characteristics of forcing and those of the climate changes induced by the forcing. For example, if a forcing excites or triggers one mode of the internal variability of the system at a particular frequency – by leading to a type of resonance – the magnitude of the response at that frequency will be large despite the fact the forcing is not predominantly strong at that frequency. Oppositely, if a threshold (value) is exceeded – near spontaneously and likely due to the evolution of the system from a very different condition to another condition – slight changes in the forcing could lead to the occurrence of large changes in the climate system. Such a transition, involving the deep ocean circulation can be proposed to explain some of the abrupt climate changes documented by the analysis of ice cores recorded in the Greenland ice sheet during the last glacial period.

[7] In general, it is known as low-pressure centers, troughs or waves having frontal or non-frontal dynamic origin with cyclonic rotation (in which the air masses moves counter clockwise by the wind) in the atmosphere.

### ***Milankovitch Cycles***

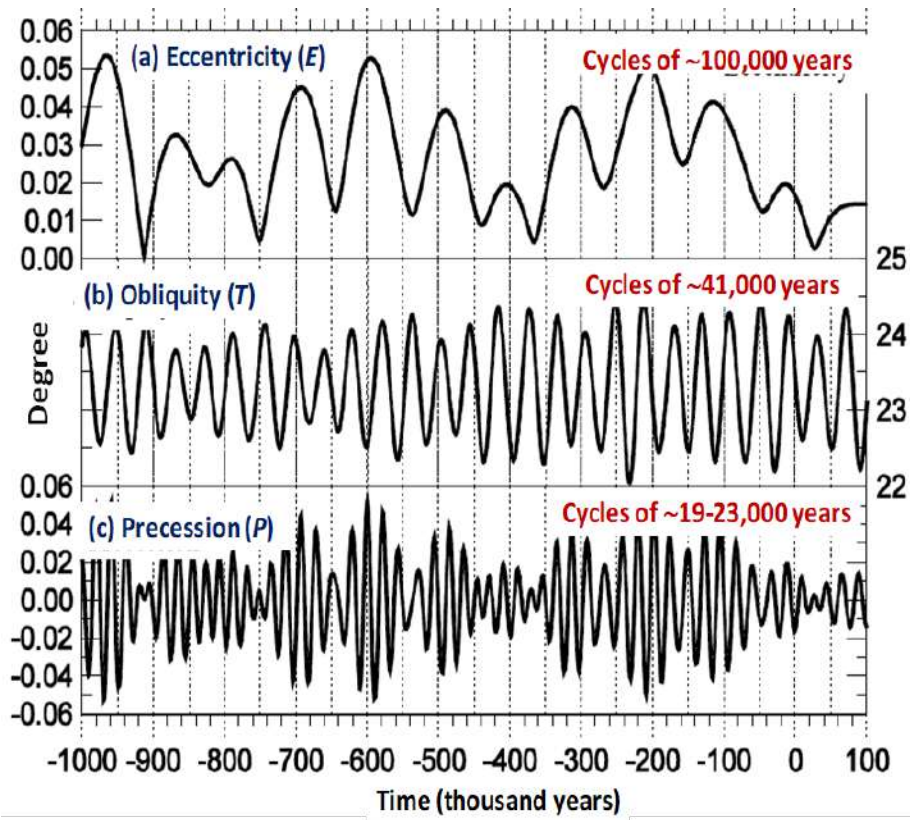
Insolation, which is defined as "*the instantaneous solar energy* ($W/m^2$) *received at a unit time on a horizontal plane with per square meter on the top of atmosphere (or on the Earth's surface, if we neglect the effect of atmosphere)*" is a function of the Sun-Earth distance and the cosine of the solar zenith distance[8]. These two variables can be computed from the time of day, the latitude, and the characteristics of the Earth's orbit. In climatology, the astronomical relations between the Earth and the Sun are called the Milankovitch Cycles. Astronomical relationships is determined by three orbital parameters: the obliquity *(tilt, T) measuring the tilt of the ecliptic*[9] *plane*[10] compared to the celestial equator (more oblique or steeper), the eccentricity *(E) of the Earth's orbit around the Sun* [e.g. more ecliptic (less roundness) or less ecliptic (more rounded)] and the climatic precession (P) *which is related to the Earth-Sun distance - namely the "perihelion time"- at the summer solstice* (Figure 2). Therefore, the major astronomical relationships that may cause global climate change include variations in the shape of the Earth's orbit (orbital forcing), obliquity and precession (at the perihelion time) (Türkeş, 2013a) (Figures 2 and 3).

[8] It is an imaginary point directly "above" a particular location, on the imaginary celestial sphere. In short, it is the zenith point at the sky from the view of a point or human on the Earth.

[9] It is the apparent path in which the Sun's visible movement on a celestial sphere seen from Earth.

[10] The axis of the Earth is inclined to 23.5 ° with respect to the plane of its orbit around the sun. Therefore, the Sun's ecliptic plane is also inclined at 23.5° with respect to the celestial equator.

***Figure 2:*** *Likely long-term variations in eccentricity (E), climatic precession (P) and obliquity (T, in degrees) for the last million years and the next 100 thousand years (zero corresponds to 1950 AD). (Re-arranged from Goosse et al.2010 according to Berger 1978) The minimum value of the climatic precession corresponds to boreal[11] (NH polar) winter (December) solstice at perihelion.*




*Changes in the orbit of the Earth*, in other words, orbital forcing, affect the distance between the Earth and the Sun. Astronomical calculations show that periodic changes in the eccentricity of the Earth closely control the seasonal and latitudinal distribution of solar insolation[12] (Türkeş, 2013a). The past and possible future changes in insolation can be calculated for millions of years at a high level of confidence.

The eccentricity of the Earth's orbit has varied over the last million years between nearly zero, corresponding nearly to a circular orbit, to 0.054° (Figures 2 and 3). Therefore, the mean annual energy received by the Earth is thus at its smallest when Earth's orbit is circular and increases with the eccentricity. However, when the changes in eccentricity are relatively small (Figures 2 and 3), very small differences occur in the average annual radiation amounts received by the Earth.

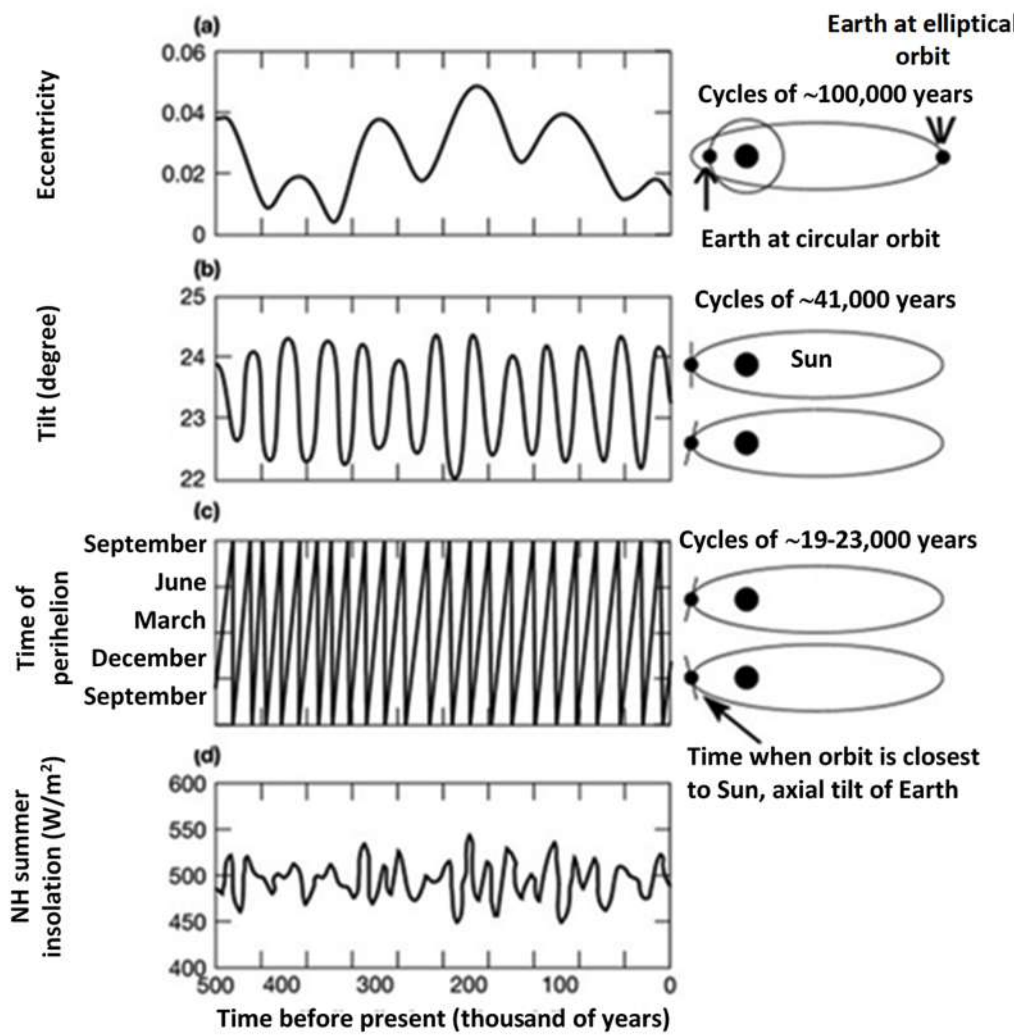
The maximum relative variation is equal to 15%, corresponding to about 0.5 W/m$^2$. The changes in the Earth's orbit (*E*) show longer half-periodicities with an

[11] It is related with northern regions or north. In physical geography and biogeography, in the south of the Arctic Circle, it is a cold climate zone consisting of birch and poplar tree communities and forests and taiga (including northern forests containing coniferous tree species, pine species, for example, pine, fir, etc.).

[12] Insolation, which is defined as the instantaneous solar energy (W/m$^2$) received at a unit time on a horizontal plane with per square meter on the top of atmosphere (or on the Earth's surface if we neglect the effect of atmosphere).

average of 100,000 years and 400,000 years (Figures 3 and 4). Changes in the shape of the orbit have a limited effect on solar insolation due to very small changes in distance between the Sun and the Earth. However, these changes also interact with seasonal effects caused by obliquity and precession, resulting in a more complex combined effect. According to our current knowledge, seasonal solar irradiation changes caused by the precession during minor orbital changes are not as large as those during wider eccentricity periods, as they were about 400,000 years ago and possibly for the next 100,000 years.

***Figure 3:*** *Likely variations in (a) eccentricity (E), (b) obliquity (T, in degrees) and c) changes in perihelion time for the last 500 thousand years (zero corresponds to 1950 AD) (Re-arranged from Goosse et al.2010 according to Berger 1978)*



The *obliquity* of the Earth is responsible for the existence of seasons on Earth. At ten thousand years of time scale, when the Earth's obliquity increases, the seasonal energy balance disturbs, and the temperature contrasts are strengthened, making winters colder and summers warmer in both hemispheres. In other words, while insolation is higher at Polar Regions during summer, it is zero during a long night at Polar Regions in winter. When the obliquity of the Earth decreases, the winters are more moderate, with cooler summers and warmer winters.

The cooler summer seasons may have led to the formation of mass ice sheets in the polar regions, resulting in less melting of snow and ice cover at higher latitudes (in the polar and sub-polar regions) and more remaining on the ground (Türkeş, 2013a). Besides, the Earth, which is also covered by more snow and ice/glaciers, also on longer time scales, creates an ice-albedo feedback mechanism in the climate system (which has a negative effect in this example), as further ISWSR reflected into space, causing additional cooling (Türkeş, 2012a and 2013b).

In the last few million years, the Earth's axial tilt has varied between about 22.5° and 24.5°, with an average half-periodicity of about 41,000 years (Figures 2 and 3). The energy response of this variation is a significant change in the average daily irradiation amount, reaching to 50 W/m$^2$ at the poles. The value of the axial tilt also affects the average annual insolation, which results in some W/m$^2$ increase in high latitudes, with a smaller decrease in size on the Equator. As a result, although the changes in the axial tilt regulate seasonal contrasts, the mean annual ISWSR changes do not have a significant effect on the global mean insolation since they have an opposite effect at low latitudes compared to high latitudes (Türkeş, 2013a).

Finally, it should be noted that the *'climatic precession'* which can be defined as a position of the seasons relative to the perihelion, also influences insolation and climate change. If Earth is closer to the Sun during the boreal summer and further away during the boreal winter, the summer in the Northern Hemisphere (NH) will be particularly warm, and the winter particularly cold and seasonal energy and temperature contrast will increase. On the other hand, if the Earth is closer to the Sun during boreal winter, the seasonal contrast will be smaller in the northern hemisphere. This effect is particularly marked if the eccentricity is large (orbit is more ecliptic). If the eccentricity is nearly zero, the distance between the Earth and the Sun is nearly constant, implying no impact of the changes in the position of the seasons (temporal location of the seasons) relative to the perihelion (Türkeş, 2013a). The climatic precession varies roughly between -0.05 and 0.05 (Figure 2 and 3). This induces changes in insolation that can be greater than 20 W/m$^2$ at all the latitudes. As a consequence, the climatic precession effect dominates the variations in insolation at low and mid-latitudes.

As a result, the precession corresponds to semi-cyclical changes or oscillations in the realization of the Earth's closest position (perihelion), with a half-periodic cyclicality of approximately 19,000 and 23,000 years. Changes in the duration and position of the seasons on the orbit regulate the latitudinal and seasonal distribution of solar insolation (Türkeş, 2013a). Seasonal changes in solar insolation are greater than the amplitude of annual average changes and can reach to 60 W/m$^2$. Due to the *'climatic precession'* movement of the Earth, the Earth was the closest to the Sun during the boreal (NH) summer 11,000 years ago, while its closest position to the Sun today corresponds to the boreal winter.

## 2.3. Brief History of Global Climate

Global climate is a highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the mutual interactions amongst them. In short, it is also called the climate system. External forcings and factors are the changes that are engaged with and affected by the sub-systems of the climate system. For example, it includes such natural events as volcanic eruptions, changes in Sun activities and changes in astronomical relations between Earth and Sun, and the anthropogenic changes in the composition of the atmosphere. Greenhouse gases and aerosols, which are emitted to the atmosphere as a result of human activities, are the main external forcing and factors that could lead to climate changes, with variable extends of impact.

The potential 'external' causes for climate change include movement of Earth's rigid tectonic plates, Sun activities, and changes in the astronomical relations between Earth and Sun. In other words, climatic changes formed by external forcing and factors occur under the control and the impact of natural events that are outside the climate system and anthropogenic forcing and factors. The astronomical relationships involve a series of periodical changes called Milankovitch cycles and could provide significant evidence in explaining long-term fluctuations in climate.

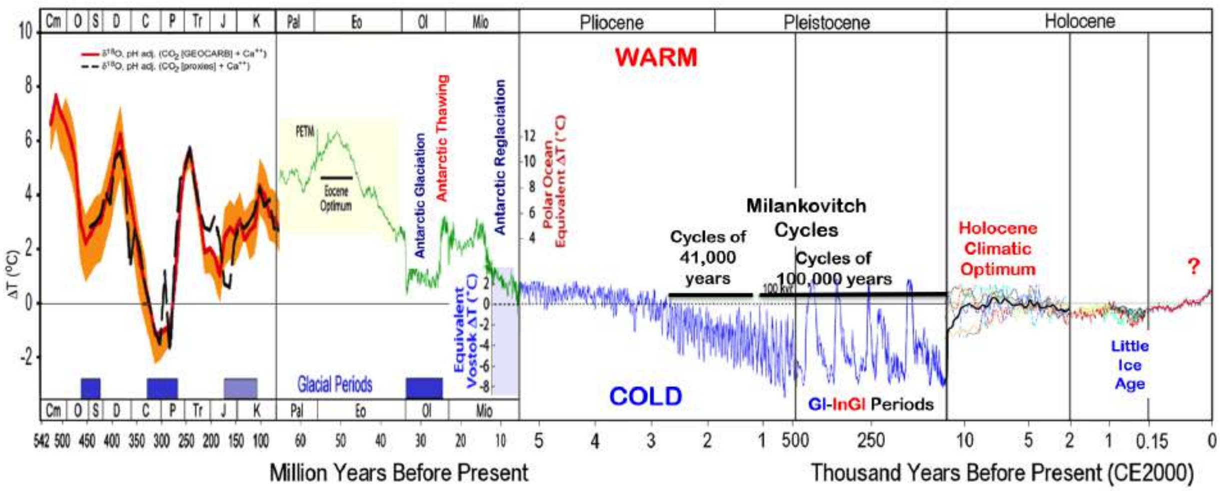
We have to admit that to investigate the prevailing climate of Earth during the first 1 billion years of Earth's history, we have to rely on indirect records and predictions. For example, in geomorphological terms (science of topographic features, formation and evolution), at least at the regional scale, whereas the existence of glacial sediments[13] in a certain geological period shows the glaciation, the existence of evaporite sedimentary rocks such as rock salt and gypsum[14] could create the evidence of a dry and warm period when vaporization was effective and of a salty/alkaline lake or a shallow sea in that period. Special climatological, hydrological, geological, and geomorphological conditions need to come together to form various mineral and rock types that can provide additional indicators of past climates and parameters of those changing climates.

However, there are still significant uncertainties on this issue. Even the best resolution (highly-detailed) climate reconstructions are regularly changed as new knowledge and techniques emerge. Evidence related to the climate of the Earth at earlier times is few. Scientific research on the issue reveals that when the Earth first formed 4.6 billion years ago, the total ISWSR was about 30% less than that coming today. If conditions such as albedo (reflection rate of incoming short-wave solar radiation), composition of the atmosphere, distance between the Earth and the Sun are considered to be the same in the past as the present, then as a result of a calculation using Earth's basic energy balance models (e.g. planetary energy balance and emission) it could be shown that the mean surface temperature should be 30 °C cooler than today.

[13] The sediments that form on the side, front and bottom of the glaciers in connection with abrasion, advancement and retreat of glaciers.

[14] It is the rock salt and sedimentary rocks such as gypsum or anhydrite formed on the shores of the old sea or lake, at the bottom or in the case of complete drying when evaporation of a shallow sea or a salty/soda lake during dry and hot periods during which the evaporation is effective in the geological history of the Earth. .

***Figure 4:*** *Demonstration of climate changes that occurred in various time scales in the geological history of Earth in the period of around 545 million years from Cambrian Period to now (Holocene), with various combined temperature time series. Re-arranged using the original drawings prepared by Robert A. Rohde for Global Warming Art (www.globalwarmingart.com/ wiki/File:65Myr_Climate_Change_Rev_png, access: June 2013)*




In the first part of earth climate history, which traces back to 700- 800 million years, despite the warming up of the global climate by continuous bombardment of small planetaries and meteorites, theoretically it would be expected that the Earth would have been very cold and frozen in a significant part of climate history under such conditions. However, this assumption contradicts the geological evidence related to the existence of a liquid ocean that existed at least 4 billion years ago. This apparent contradiction is called as '*faint early Sun paradox*'. The main reason for this paradox could be the existence of a stronger greenhouse effect that occurred in the early times of the Earth. The atmosphere at those times was profoundly different from the atmosphere of today due to higher $CO_2$ concentration. It is foreseen that the $CO_2$ concentration in the atmosphere of that time was 100 times higher compared to present-day value, containing almost no oxygen ($O_2$) molecule. In the case of absence of oxygen in the atmosphere, $CH_4$, which is a gas with effective radiation such as $CO_2$ (greenhouse gas), was not oxidizing as fast as it is doing today, and its concentration in the atmosphere was much higher than today. Climate changes that had occurred in various time scales in the geological and climate history of 545 million years of Earth, from the start of Palaeozoic Era, in other words, the Cambrian Period, are shown in Figure 4 with temperature time series. Whereas in Figure 4, present-day is represented as 0 (zero) in terms of time, today's climate is also shown as 0 (zero) to better monitor and compare the changes and deviations. On the other hand, instead of a real logarithmic scale in the drawing of time series, a very approximate logarithmic scale was used by showing each with a more detailed linear scale towards the present day.

During the last 65 million years, the $CO_2$ concentration in the atmosphere slowly decreased to below 300 ppmv in Pleistocene Epoch from 1000 ppmv in Paleocene Epoch and early Eocene Epoch. A significant part of the Quaternary Period, which lasted approximately 2.588 million years, -except the Holocene Epoch with a length of 0.0117 million or around 11.000 years that is closed to present- corresponds to the Pleistocene Epoch. As one would expect, this long-lasting slow decreasing, is partially linked to the volcanic gas and ash emissions that have increased due to plate movements and mountain formations (orogenesis) – the volcanic eruptions have gradually decreased since that time – and the changes in the decomposition rate of silicate rocks particularly in Paleocene and Eocene Epochs. According to our current knowledge, the decrease in $CO_2$ concentration must have been connected to the cooling following the warm conditions in the *Early Eocene Climatic Optimum* period that occurred between 52 and 50 million years ago (Figure 4). This significant shift in the climate is considered as a "*transition from a warm global climate to a cold global climate, or to an icehouse*", namely from strong greenhouse effect climate to one where continental ice sheets existed start from around 35 million years back in the Antarctic and 3 million years back in Greenland (together with relatively colder or relatively warmer times in interim periods). The climate reconstructions in this period rely mostly on changes in the oxygen isotope components of shells (shells with $CaCO_3$ component) of planktonic (pelagic) and benthic[15] living small marine organisms, referred commonly to as foraminifera (in some recent studies, 'foraminiferida').

According to Milankovitch or orbital theory of ice ages, the ice ages in the Pleistocene Epoch of Quaternary Period were generally triggered by a decrease in summer insolation at higher latitudes in Northern Hemisphere (NH).

As a result of this, snowing during the winter season is effective for a longer time during the whole year, and snow accumulates to create continental ice sheets and Alpine mountain (cap and valley) glaciers in NH. Similarly, it is accepted that strong high latitude insolation periods in NH determined by the orbital changes of Earth (orbital forcing), triggers fast deglaciation[16] and climate changes related to that, which in turn triggers sea level rise. While these orbital forcings determine the course of climate change, it is seen that major responses are determined by strong feedbacks that reinforce orbital forcings.

The chemical analysis of the air trapped in the ice samples (ice cores) taken from Antarctic glacier has demonstrated that $CH_4$, $CO_2$ and $N_2O$ concentrations in the atmosphere could be in well-matched with deuterium[17] (δD) alterations that are a good proxy record and indicator for local temperature conditions in the last 650 thousand-years period of Pleistocene Epoch, which corresponds approximately to Middle and Late Pleistocene Epochs, and the related glacial and interglacial periods. The benthic oxygen 18 isotope ($\delta^{18}O$) is a good proxy record and indicator for changes in global ice volume: a high benthic $\delta^{18}O$ value corresponds to a smaller ice volume. Between the warm periods that correspond to more positive deuterium values, the long and apparent ice ages where more negative deuterium values prevail. As a result, using the information recorded in Antarctic glacier cores, the fluctuation between long ice ages and relatively shorter interglacial ages that prevailed in Middle and Late Pleistocene Epochs have been documented (Figure 4).

[15] Relates to the ecological zone (life zone) located at the lowest level or bottom of a water mass such as ocean, sea, lake or river. Organisms living in this zone are called benthic or living organisms..

[16] The melting and retreat of land glaciers in interglacial ages or in warm climate periods.

[17] One of the stable isotopes that include 1 proton (+) and 1 neutron in the nucleus of Hydrogen element.

***Figure 5:*** *Geographical Distribution of Ice Sheets Cover at the Last Glacial Maximum of Late Pleistocene Würm Glaciation in the North of Eurasia (Mangerud et al., 2004).*

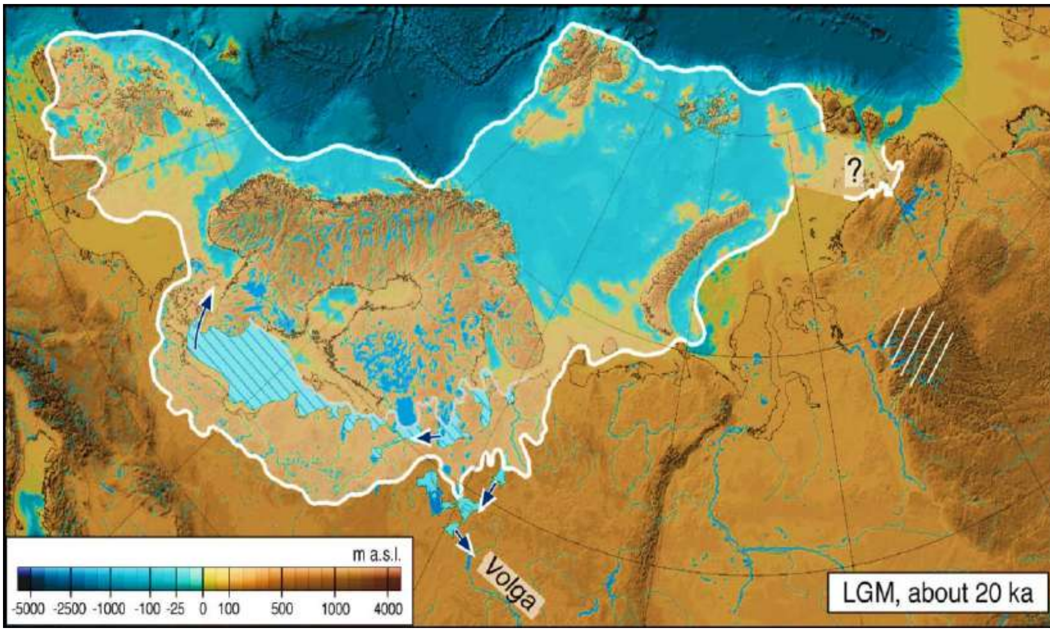
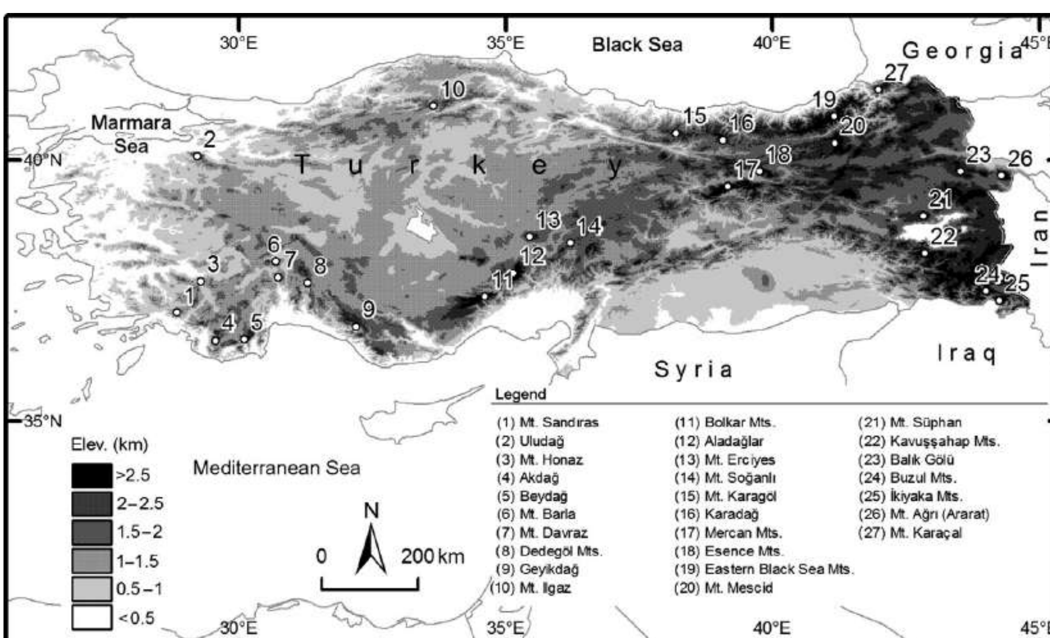


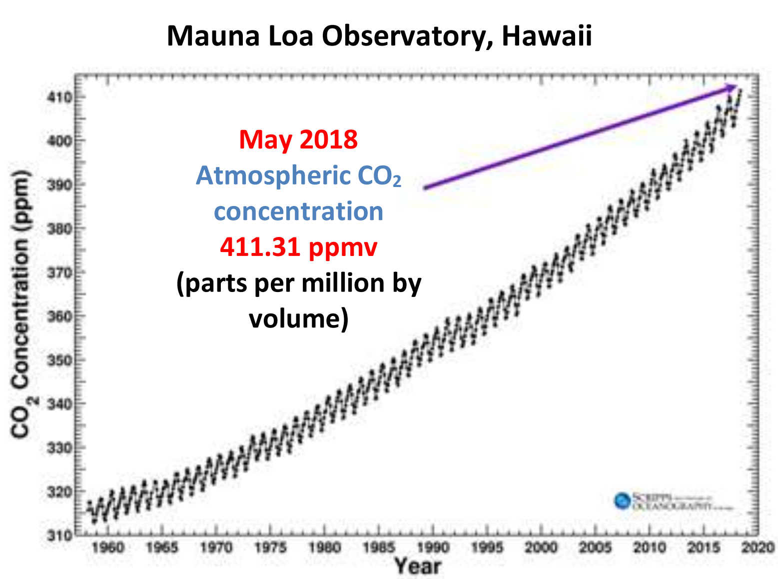

***Figure 6:*** *Names and Geographical Distribution of the Glaciated Mountains in Quaternary Glaciation in Turkey (Sarıkaya et al., 2011).*



Modern people live in the Holocene Epoch, which is the last of the ice ages of the Pleistocene Epoch according to the geological time scale. The best known of the Pleistocene glaciation is called *'Würm Maximum'* or *'Last Glacial Maximum* (LGM), which is the last and most severe one that occurred approximately 20-22 thousand years ago. In the last glacial age, glacier shields covered the majority of the continents at high latitudes and they extend south to about 40° latitude in the regions of North America, Europe and Asia (Figure 5) where topographically favourable. In the same period in mountainous areas [e.g. in the Alps, at the summits of high mountains of the eastern Black Sea and the Taurus Mountains and the Uludağ, Erciyes, Ağrı, Süphan, Cilo, etc. (Figure 6). Alpine valley glaciers and cap glaciers have also grown in terms of area and volume, and have expanded to hundreds of meters below compared to today in relation to the elevation of the mountain and permanent snow boundary.

On the other hand, due to the accumulation of atmospheric water on the mainland in the form of ice, the average sea level was about 120 m lower than today due to the addition of new land to the Earth. For example, there were land bridges between North America and Asia along the Bering Strait and others between the European mainland and Britain (Figure 5). At the same time, the permafrost[18] soils and the tundra biome of the higher latitudes had expanded into further south than today, and the distribution area of the tropical rain forest biome was relatively narrowed. Tropical climates were 2-4 ° C colder on the land and likely similar conditions had emerged in the oceans. Sea ices (e.g., the Arctic and the Antarctic) were more prevalent in the higher latitude regions, as cooling and glaciation were stronger in those regions. In general, it is estimated that the global mean surface temperature was probably colder at around 4-7 °C than today (Figure 4).

***Figure 7:*** *Monthly variations and long-term trend of $CO_2$ concentration in the atmosphere between the years of 1958 and 2018.*




[18] It is the soil that remains frozen for two or more years and occurs where the temperature stays below 0 °C for years. The temperature of the soil that slightly below the surface can never exceed the freezing temperature. In summer, only the top few cm of the soil melts; this is called the active layer. The regions around the north pole of the Earth have been demonstrating permafrost characteristics for thousands of years.

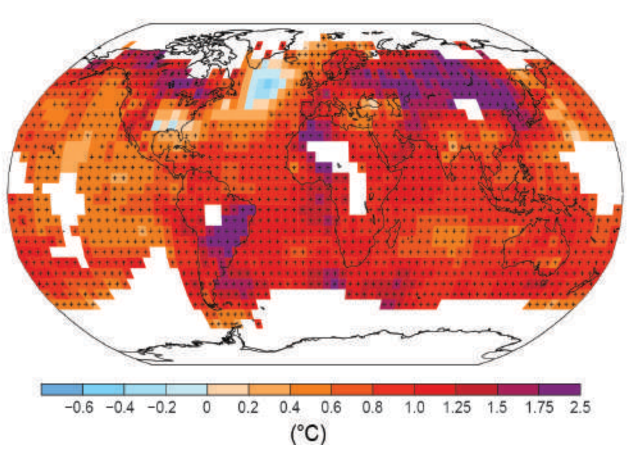
## 2.4. Anthropogenic Climate Change and Global Warming

The increase in human-made greenhouse gas accumulations in the atmosphere is ongoing since the industrial revolution. The importance of $CO_2$ is better understood, especially when considering the magnitude of its concentration in the atmosphere, the rate of increase, the life span of 50-200 years, and the ability to absorb most of the outgoing long-wave infrared ground radiation. The $CO_2$ accumulation at the Earth's atmosphere has been increasing very rapidly. When the average monthly $CO^2$ time series is analysed, the annual mean $CO_2$ concentration in the atmosphere, which was about 280 ppmv (one molecule per million volume or one million per particle) before the industrial revolution and about 315 ppmv in 1958, was about 394 ppmv in 2012 and reached to 411 ppmv in May 2018 (Türkeş, 2013b, 2018) (Figure 7). The current level of $CO_2$ concentration in the atmosphere is well above the natural $CO_2$ concentration levels (ranging from about 180 to 300 ppmv) during the past 700,000-years record. These increases in greenhouse gas concentrations weaken the Earth's cooling efficiency via outgoing long-wave infrared radiation, resulting in a positive radiative forcing that tends to heat Earth further.

Therefore, the positive contribution to the energy balance of the Earth/atmosphere system is called the enhanced greenhouse effect (Türkeş, 2008a and 2008b). It means that the natural greenhouse effect, which has been working for hundreds of millions of years thanks to natural greenhouse gases (water vapour, $CO_2$, $CH_4$, $N_2O$ and $O_3$) in the Earth's atmosphere, is strengthened.

Global warming could be defined as temperature increase, since the industrial revolution, on the surface and lower layers of the atmosphere due to the enhancement of the natural greenhouse effect in conjunction with increasing greenhouse gases accumulations as a result of the human activities especially the burning of fossil fuels, deforestation, agricultural activities, and industrial processes and urbanisation (Türkeş, 2008b, 2012a). As can be understood from the definition, greenhouse gases that cause human-induced climate change and global warming arise mostly from burning fossil fuels (energy and cycle), industry (energy-related; non-energy such as chemical processes and cement production, etc. ), transportation, land-use change, waste management and agricultural (energy-related; stubble burning, rice production, livestock and fertilization etc. non-energy).

***Figure 8:*** *Spatial distribution of observed changes in mean annual surface temperatures according to linear trend rates for the period 1901-2012 (IPCC, 2013).*




2
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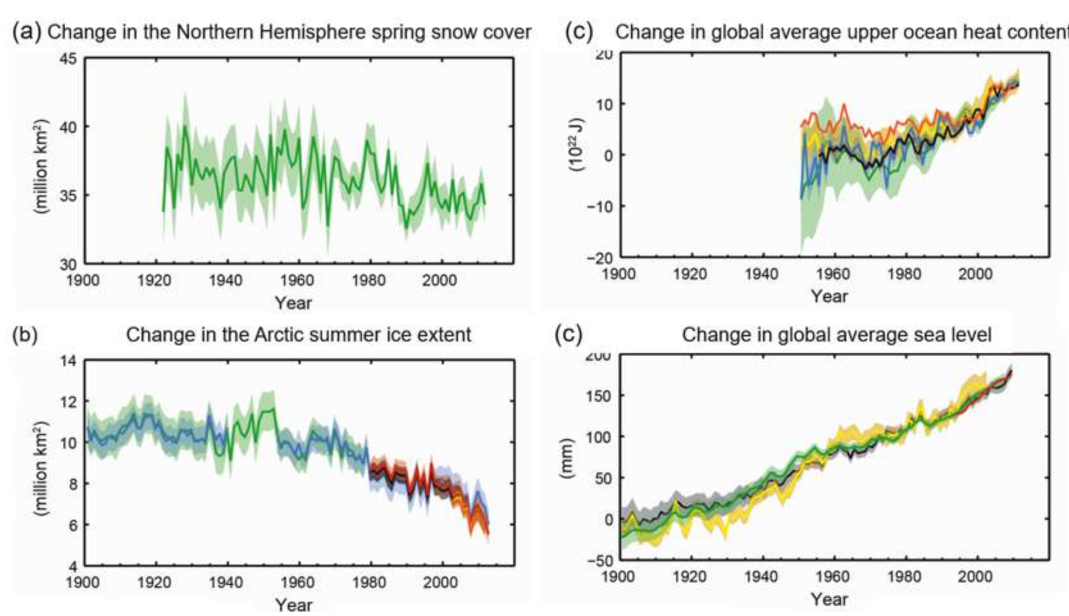
# 3. OBSERVED CLIMATE CHANGES ON EARTH AND IN TURKEY

The most important result of the enhanced greenhouse effect which has become stronger as a result of gradual increase of the concentration of greenhouse gases in the atmosphere after the industrial revolution due to human activities, is the occurrence of additional positive radiative forcing on the energy balance of the Earth, making the planet's climate warmer (Figure 7a and 8, drier in some regions (Figure 10) and more variable. On the other hand, both at the global scale and regional scale, climate change causes the occurrence of important changes in the frequency, magnitude, spatial distribution, length and timing of extreme weather and climate conditions. For example, precipitation showed high variability both in spatial and temporal aspects on the global scale in the 1900-2012 period, and drought and increasing precipitation trends on a regional scale were observed (Figure 10). Whereas a *significant rising trend* was observed in eastern parts of North and South America, central regions of Northern Europe and Asia, *significant drought or downward trend* were effective in the Sahel, the Mediterranean basin, including Turkey, a part of South Asia and Southern Africa (IPCC, 2013; Türkeş, 2012a and 2012b, 2013b). Moreover, substantial increases have been observed regarding *extreme precipitation events* (extreme high and low precipitation, etc.) and *average air temperatures* in many regions of the world and Turkey (IPCC, 2013; Türkeş, 2013c and 2014).

***Figure 9:** Long-term trends and inter-annual variations observed in (a) the area covered by the spring snow cover of the Northern Hemisphere, (b) global average upper ocean heat content, (c) Arctic sea ice extent, and (d) global average sea level change (IPCC, 2013).*



## 3.1 Observed Changes in Global Climate

According to the "Climate Change 2013: The Physical Science Basis" report published by the Intergovernmental Panel on Climate Change (IPCC, 2013), warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. Global mean surface temperature data showed a linear increase of 0.89 °C [in the 0.69 - 1.08 °C confidence interval] between 1901 and 2010. During this period, the troposphere, which constitutes almost the Earth's entire surface (Figure 8) and the lowest layer of the atmosphere in which life and weather events occur, has been globally warmed since the mid-20th century. Furthermore, indirect old climate data indicate that the, in the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased in the atmosphere (Figure 9). As expected, global ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (Figure 9b). It is virtually certain that the upper ocean (0−700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971. The increase in upper ocean heat content during this time period estimated from a linear trend is likely 17 [15-19] × 1022 J (IPCC, 2013) (Figure 9b). In addition, it is very likely that regions of high salinity where evaporation dominates have become more saline, while regions of low salinity where precipitation dominates have become fresher since the 1950s. These regional trends in ocean salinity provide indirect evidence that evaporation and precipitation over the oceans have changed.

Over the last 20 years, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (Figures 9a and 9c). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901 to 2010, global mean sea level rose by 19 cm [0.17 to 0.21] (IPCC, 2013) (Figure 9d). Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise. Past sea level changes are thought to be caused by different factors (e.g., changes in the relationship between Earth and the Sun) (IPCC, 2013).

***Figure 10:*** *The spatial distribution patterns of precipitation changes observed (a) in 1901 - 2010 and (b) in 1951 – 2010, according to linear trend calculations (IPCC, 2013).*

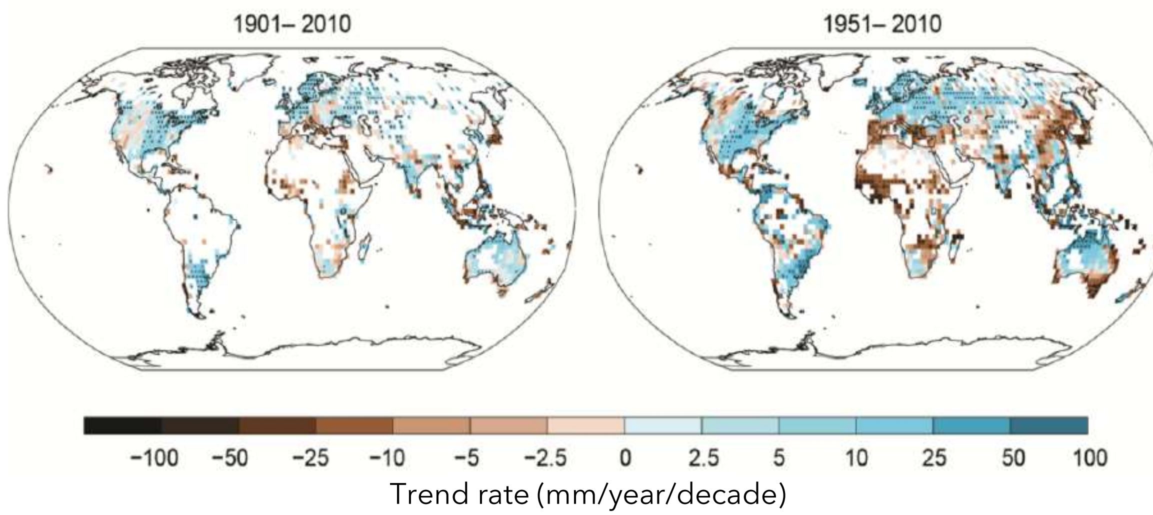
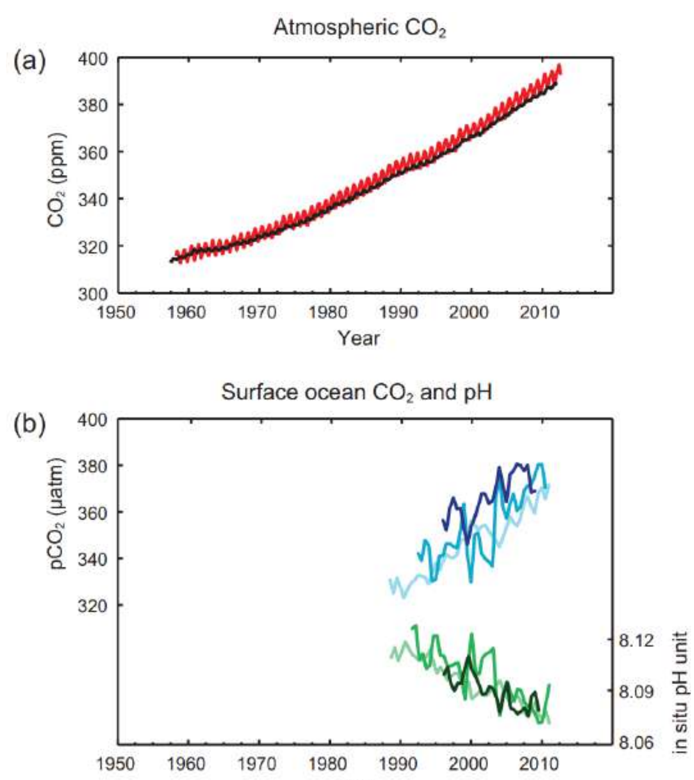



***Figure 11:*** *The observed multiple indicators of the global carbon cycle are: (a) Changes in atmospheric $CO_2$ concentration observed in Mauna Loa and the South Pole since 1958 and (b) Changes observed, since the beginning of 1990s, in partial pressure of dissolved $CO_2$ in ocean surface and in pH levels which is a measure of acidity of ocean water (IPCC, 2013).*



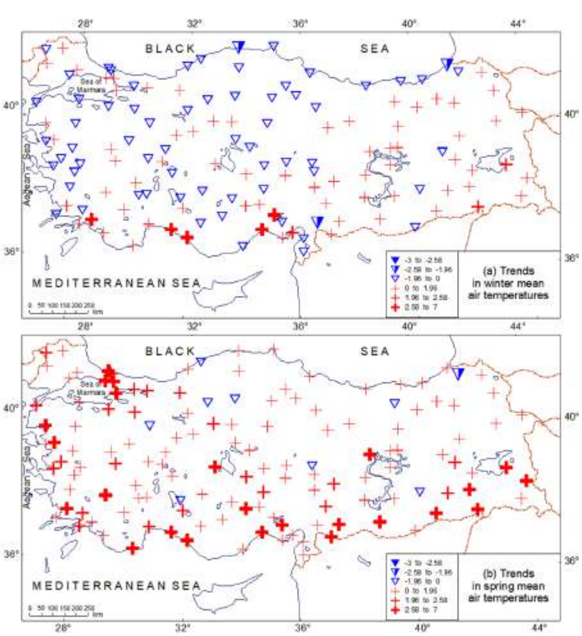
Precipitation has increased since 1901 in the land areas of the North Hemisphere. In the subtropical and certain tropical regions, which include the Mediterranean Basin and the west and south regions of Turkey where Mediterranean climate prevails, significant decreases have been observed in the amount of precipitation (Figure 10).

*Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heatwaves has increased in large parts of Europe, Asia and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe.*

The atmospheric concentrations of $CO_2$, $CH_4$, and $N_2O$ gases has reached a level that it has never reached during the past 800,000 years. The atmospheric concentrations of the greenhouse gases $CO_2$ (Figure 11a), $CH_4$, and $N_2O$ have all increased since 1750 due to human activity (primarily emissions from fossil fuel combustion and secondarily net emissions from land-use change). In 2011 the concentrations of these greenhouse gases were 391 ppm (parts per million), 1803 ppb (parts per billion), and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively.

The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (Figure 11b).

***Figure 12-1:*** *Spatial distribution patterns of long-term trends of average air temperature in Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method, (a) winter and (b) spring season (Türkeş, 2016). The inverted triangle icons indicate decreasing trends in air temperature series, while the plus icons indicate increasing trends in time-series. Larger triangle symbols with dotted and filled inside (relatively thick and thicker plus symbols) demonstrate the decrease (increase) trends at the 5% and 1% significance level in the series according to the legend that includes map symbols corresponding to the M-K test statistics u(t).*

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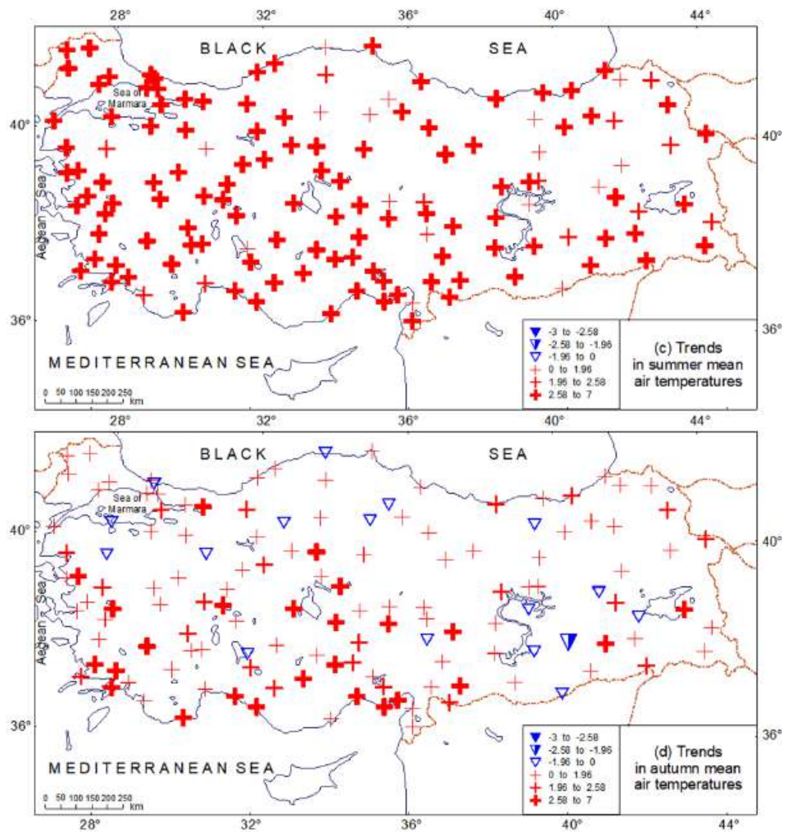
## 3.2. Observed Changes in Turkey's Climate

In this section, long term trends and changes in Turkey's precipitation and air temperature series were analysed using the monthly average, monthly average maximum (highest) and monthly average minimum (lowest) air temperature data (°C) recorded in the climatology and meteorological stations of the General Directorate of Meteorology (MGM) during 1950-2010 period, as well the results of statistical and climatological time series analysis of monthly total precipitation (mm or kg/$m^2$) (Türkeş, 2013b). In order to determine trends in station data, Mann-Kendall (M-K) rank correlation coefficient method was applied to a long-term time series (Sneyers, 1990; Türkeş et al., 2002). The data of 138 stations were used for statistical analysis and significance test of monthly average air temperature and total precipitation trends, taking into account conditions and rules such as data uniformity, continuity, monthly missing data amount not exceeding 5% of the total data at that station etc. (Türkeş, 1996, 1998, 1999). For determining the average maximum and average minimum air temperature series, detailed homogeneity, and the time series of 70 stations, which have the longest temperature observations in Turkey as determined by Türkeş et al. (2002) as a result of randomness analysis, were used. Although the analysis is performed for seasonal and annual series of all data, annual and seasonal M-K results are used here for air temperature and total precipitation, and only the annual M-K results were provided for the average maximum and average minimum air temperatures.

### 3.2.1. Observed Changes and Trends in Air Temperatures

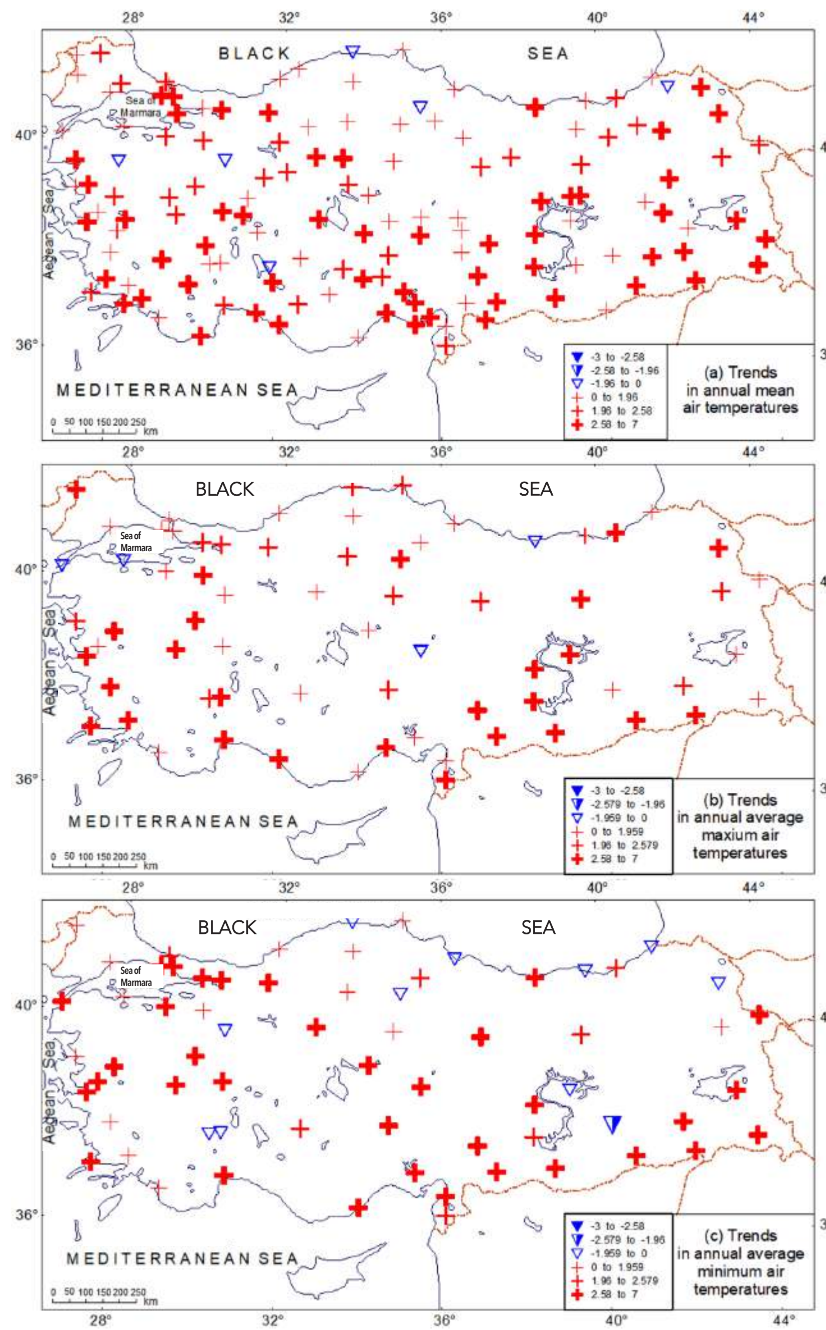
When the long term trends in seasonal average air temperatures are analysed, it could be seen that there are both increase and decrease trends in the winter season, part of which is statistically significant (Figure 12.1a). According to the results of *M-K test*, the statistically significant warming trends generally prevail in the Mediterranean Region. Cooling trends are seen in the Black Sea Region and interior and west regions, of which small part is statistically significant. Spring average air temperatures demonstrate a trend of increase in most parts of Turkey, excluding a couple of stations (Figure 12.1a) Warming trends observed, especially in Marmara, Aegean, Mediterranean, Central Anatolia and South-eastern Anatolia regions are statistically significant. It is to be highlighted that warming trends are significant and climatically important at a significance level of 1% in Istanbul area (where urbanisation is rapid and widespread, and the urban heat island effects are strong), coastal stations of Aegean and Mediterranean regions and South-Eastern Anatolia Region (Figure 12.1.b).

***Figure 12-2:*** *Spatial distribution patterns of long-term trends of average air temperature in Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method, (c) summer and (d) autumn season (Türkeş, 2016). The map legend is the same as Figure 12-1.*



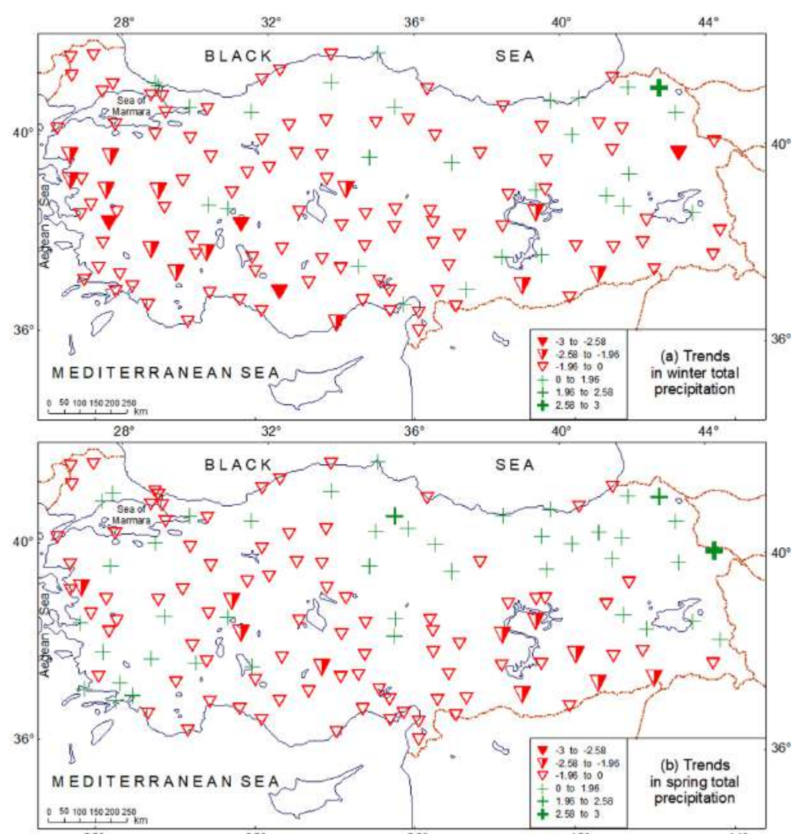

The most important difference of the new study, results of which are given here, from the previous air temperature trend studies conducted for Turkey, is that the gradually strengthening warming trends are seen in the summer and autumn seasons (Figure 12.2c and 12.2d). Strong warming trends seen in the summer season are statistically significant, with a significance level of 1% in most of the stations (Figure 12.2c). This situation is a result that should be emphasized from the point of strengthening of signals of regional climate change. According to time series analysis, the warming trend observed has accelerated with the 1980s at almost all stations regardless of the level of urbanisation, and with a significant breakthrough, it turned into an important warm period in the last 20 years (time series drawings are not given here). The transition to a period in which warmer conditions prevailed (climate change signal) with respect to the long-term average occurred in the mid-1980s for certain stations and others in the early 1990s. Autumn average temperatures also tend to warm mostly (Figure 12.2d). While the cooling tendency observed in several stations only one of them is statistically, the observed warming trends are statistically significant in the Aegean, Mediterranean and Central Anatolia regions with a majority of 1% significance level.

***Figure 13:*** *Spatial distribution patterns of long-term trends of average air temperature in Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method, (a) annual mean, (b) annual average maximum, and (c) annual average minimum (Türkeş, 2016). The map legend is the same as Figure 12-1.*



Similar to the analysis of seasonal temperatures (not all analysis results of seasonal temperature are provided here), the results of observed temperature trends for Turkey used for the analysis of average, annual average maximum and annual average minimum temperatures. The analysis shows there is a further strengthening warming trend for them (Figure 13a, 13b and 13c). A significant warming trend is seen in most of the stations regarding annual average, annual average maximum and annual average minimum air temperatures, except some stations which are characterized by a decreasing trend with a random distribution. The observed warming tendency is statistically significant in most stations. Weak warming and cooling trends are distributed throughout the Black Sea region and northern parts of Central and Eastern Anatolia. Statistically, significant warming signals show a very significant spatial consistency pattern. All these results demonstrate that, among other things, global warming which is one of the most significant results of anthropogenic global climate change which is relatively easier to be identified, takes effect in Turkey.

***Figure 14-1:*** *Spatial distribution patterns of long-term trends of average air temperature in Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method, (a) winter and (b) spring season (Türkeş, 2016). The invert triangle symbols demonstrate the decrease trend in total precipitation series, and the plus symbols demonstrate the increase trends in total precipitation series. Bigger triangle symbols with dotted and filled inside (relatively thick and thicker plus symbols) demonstrate the decrease (increase) trends at the 5% and 1% significance level in the series according to the legend that includes map symbols corresponding to the M-K test statistics u(t).*



### 3.2.2. Observed Changes and Trends in Total Precipitation

According to World Meteorology Organization (WMO), "an area is accepted to be affected from drought when the total precipitation of a given year is lower than 60% of the average amount (minimum 30 years) or normal precipitation with a period of minimum 2 consecutive years in more than half (50%) of an area (country, region, section, district, basin etc.)". According to this definition and the results of various studies based on drought assessment/monitoring methods, an drought which started in 2012 in some parts of Central Anatolia and Eastern Anatolia regions of Turkey, continued by becoming effective in a wider area in 2013 and became stronger by merging with the summer drought of 2013 (which started as meteorological and turned into agricultural and hydrological drought in various regions from the point of various systems), was effective in a significant part of Turkey in the first half of 2014 (Türkeş 2014b; Türkeş and Yıldız, 2014).

When the literature related to the subject is analysed, it could be understood that the climate zones between very arid and semi-humid are more exposed to the effects of strong changes in climate. Short term changes and long term fluctuations in the regional precipitation are a well-known characteristic of arid and semi-arid lands. For example, the amount of precipitation in the Sahara and Sahel regions of Africa has decreased significantly starting from the 1960s. Despite the fact that some arid periods occurred in the last geological period (Quaternary) and the historical past, it was recorded that this last arid period in the Sahara was more tending towards a drought at a continental scale. The long-term downward trend in precipitation and significant drought conditions, especially starting from the beginning of the 1970s, has been effective in an important part of the Mediterranean Basin so as to include subtropical zone and Turkey (Türkeş, 2008b, 2013b, 2014 and 2014b).

In fact, if a comparison is made, it could be seen that the seasonal and annual precipitation trends are not as strong as trends seen in air temperatures in Turkey (see Figure 14-1, 14-2 and 15). As in many parts of the world, changes in precipitation are not showing long-term trends, but rather they are in various forms of change and fluctuation and, in the forms of significant changes in the frequency and extent of arid and humid periods (Tatlı and Türkeş, 2008 and 2011; Trenberth *et al*., 2007; Trigo et al., 2006; Türkeş, 1996, 1998, 2011a, 2011b and 2013b; Türkeş and Erlat, 2003, 2005; Türkeş and Tatlı, 2009; Türkeş *et al.*, 2009a and 2009b, etc.). The spatial variability of precipitation changes is also strong. Aegean, Mediterranean, Marmara, Central and South-eastern Anatolia regions were most affected in Turkey from mentioned drought tendency.

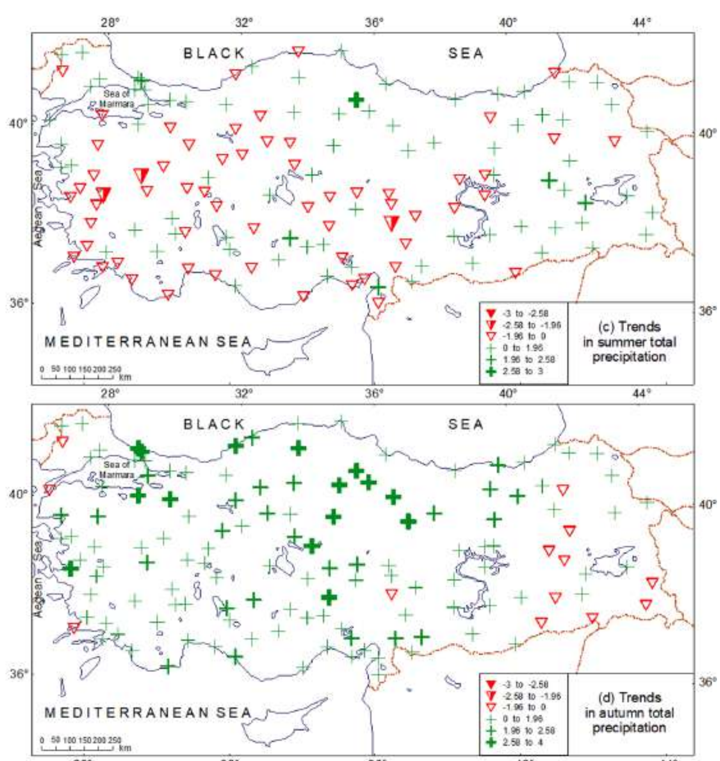
When particularly the changes in winter seasons and annual precipitation in the last 40 years are taken into account, the most severe and widespread droughts in Turkey occurred in 1971-1974, 1983-1984, 1989-1990 and 2007-2008 periods as well as years 1996 and 2001 (Tatlı and Türkeş, 2008; Türkeş, 1996, 1998, 1999, 2008b and 2011a; Türkeş and Erlat, 2003 and 2005; Türkeş and Tatlı, 2009; Türkeş *et al*., 2009a and 2009b, etc.). Following the 2007-2008 drought which was effective in most of Turkey and led to the occurrence of intense water gap and insufficiency, in 2009-2011 period, more humid/rainy conditions (rainy or wet period) prevailed when it is compared to long term average values (Türkeş, 2012b, 2013b, 2014a and 2014b). However, the meteorological droughts that started to be effective again in some parts of the continental Central Anatolia and East Anatolia in 2012, combined with the summer drought, lead to a drought season that ranged from medium to extraordinary drought in the continental Central Anatolia and Eastern Anatolia regions and Central and Eastern

Mediterranean, East Marmara and Central Black Sea regions.

As a consequence, there has been a decrease of 37.0% compared to long years average and of 47.5% compared to the year 2013 in the cumulative precipitation amount calculated for overall Turkey between 01 October 2013 – 17 January 2014. The drought of 2013-2014 has evolved from being a meteorological drought to agricultural and hydrological droughts in many regions and locations, as it could be apparently seen by looking at the SPI distribution patterns calculated for 6-month or longer time scales (Türkeş, 2014a and 2014b).

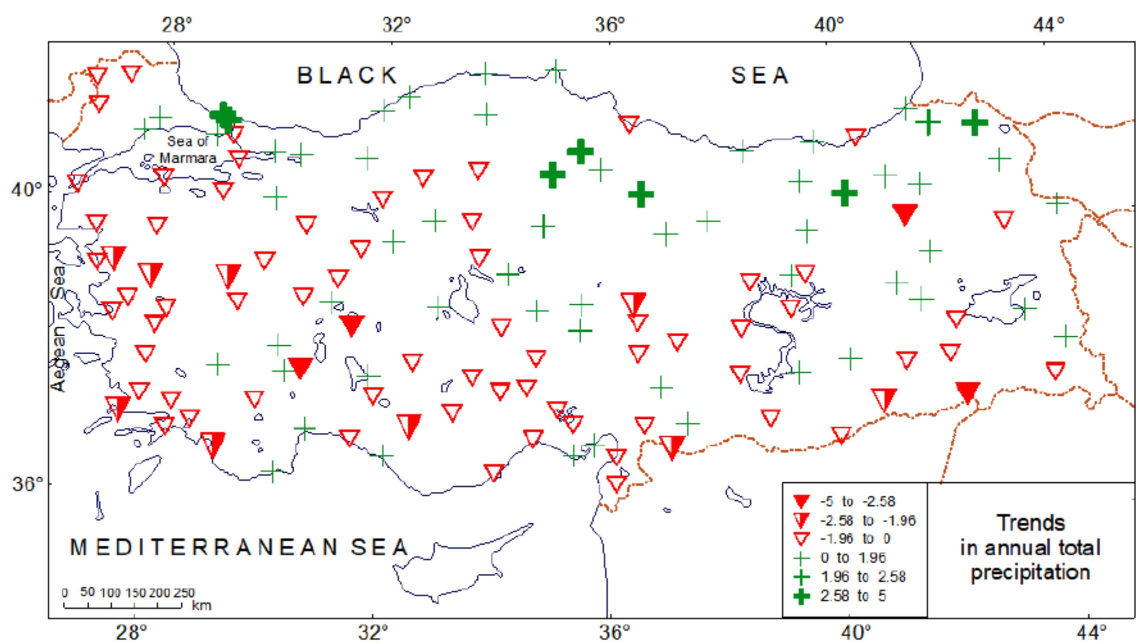
When the long-term trends and changes in Turkey's precipitation are examined, it could be seen that in general, the total winter and spring precipitation has been a significant decrease trend in Marmara, Aegean, Mediterranean and South-eastern Anatolia regions where Mediterranean precipitation regime of Turkey prevails, and in the central and south sections of Central and Eastern Anatolia regions. Some of the drought trends observed in the Aegean, Mediterranean and South-eastern Anatolia regions in winter are statistically significant (Figure 14-1a). These results are generally consistent with studies conducted for Turkey on precipitation trends and changes. In other words, drought trend seen the winter season in Turkey, especially in western, southern and continental central-southern regions, continues despite the existence of more rainy (humid) conditions than the average prevailing in the last 2 years (2008/2009-2009/2010) (Türkeş, 2014b).

***Figure 14-2:*** *Spatial distribution patterns of long-term trends of average air temperature in Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method, (c) summer and (d) autumn amounts (Türkeş, 2016). The map legend is the same as Figure 14-1.*



Both increasing and decreasing trends prevail in summer, some of which are statistically significant, which is similar to the results of previous studies (Figure 14-2c). In autumn, apart from the previous studies, it could be seen that the previously observed trends have become stronger and the number of stations demonstrating an upward trend has increased. In autumn, there is a prevailing increase in precipitation except for the area that covers the south-eastern corner of Turkey. The increase trends observed are statistically significant, with most having a significance level of 1% in Central Anatolia, Western Black Sea, and South Marmara and North Aegean regions. These rising trends may have been due to the more humid conditions than the long-term average observed in recent years in connection with the NAO negative phase, defined as the large-scale atmospheric pressure fluctuation between subtropical high pressure on the Azores and mid-latitude low pressure on Greenland and Iceland (Türkeş, 2011a and 2012a).

***Figure 15:*** *Spatial distribution patterns of long-term trends in annual total precipitation amounts of Turkey according to the significance test of the Mann-Kendall (M-K) rank correlation coefficient method (Türkeş, 2016). The map legend is the same as Figure 14-1.*



Regarding annual total precipitation in Turkey, mainly as a reflection of trends and anticipated changes in winter and autumn rainfall, a declining trend seen in western and southern regions where Mediterranean precipitation regime prevails (Figure 15). On the other hand, there is an increasing trend in annual total precipitation in the north and east parts of the Black Sea Region and Central and Eastern Anatolia regions as well as Tekirdağ and Istanbul areas of Thrace. Only a few of the observed upward and downward trends are statistically significant.

Besides, new findings derived from long-term climatologic and meteorological observations demonstrate that significant changes have emerged in the daily extreme weather temperatures (e.g., the highest and the lowest temperatures, tropical and summer days, etc.), in the number of frost days and the frequency and length of heatwaves since the 1950s. According to IPCC (2013), "*changes in many extreme weather and climate events have been observed since about 1950. The number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. The frequency of heatwaves has increased in large parts of Europe, Asia and Australia*." Such changes, generally in East Mediterranean and Turkey, are experienced as the significant decrease in the number of frost days and snowy days since the 1990s; increase in number of warm days and nights as well as the increase in lowest night and the highest daytime air temperatures; and the increase in the daytime highest and night lowest temperature differences such that important part of them is statistically significant, (Erlat and Türkeş, 2008, 2012 and 2013; Türkeş *et al*., 2002; Türkeş and Sümer, 2004; Kartum *et al*., 2011; vb.).

In other words, in the last 25-year period in Turkey, the temperature has significantly changed towards milder and warmer conditions and there occurred significant changes in the frequency and magnitude of heatwaves (Türkeş, 2008b, 2012a, 2013b).

In addition to these, as it could be seen in the next section, it is expected that the increases in the atmospheric concentration of greenhouse gases will lead to regional and global changes in surface temperatures, lower-troposphere air temperatures, evaporation, cloud, precipitation, and humidity variables. Projections of global and regional model simulations related to future climate and climate changes for Turkey and regions enclosing it demonstrates that in Turkey *the rainfall and snow precipitation will decrease, air temperatures and evaporation will increase, the frequency and length of heatwaves and drought will increase, etc. and other significant climatic changes will take place, and Turkey will be negatively affected from the climate change in the future together with many countries in the Mediterranean basin* (e.g. IPCC, 2007, 2013; Türkeş, 2012a, 2013b and 2014a, etc.). For all these reasons, to reduce or prevent the effects of climate change and, at least in terms of adaptation, predicting the future climate of Turkey is vital.

## 3.3. Observed Changes and Trends in Extreme Weather and Climate Events

Extreme weather/climate events are linked to the natural variability and chaotic characteristics of the climate system itself. In order to define a weather and climate event as “extreme”, the occurrence value of some important meteorological variables needs to be located near the upper (or lower) ends of the observed range according to the statistical distribution or need to reach a stage above the existing high threshold value. Although they are not defined as statistically “rare,” weather or climatic events that have a major negative impact on ecosystems or society are also considered as an extreme (Türkeş and Erlat, 2018).

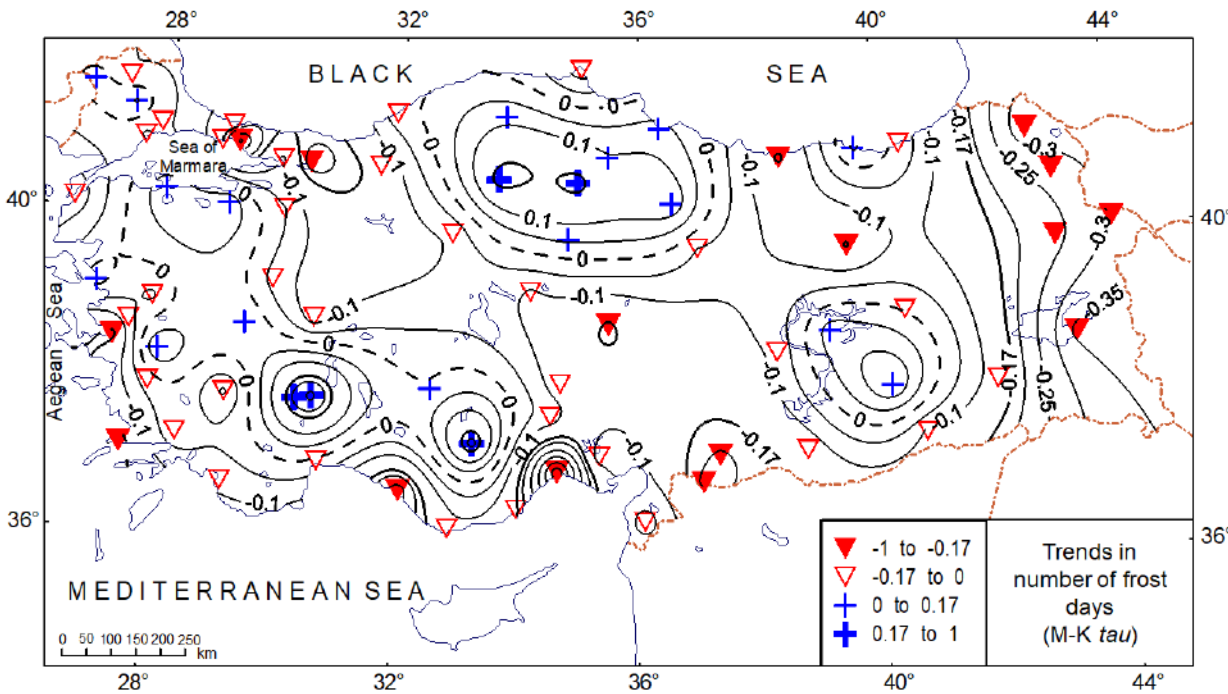
Though not occurring frequently, extreme weather and climatic events have a major impact on economic conditions and human health, particularly in sectors such as agriculture and food security.

Compared to the past, the growing population and the infrastructure facilities that becoming more complex, predominantly concentrated in cities and coasts, also increase the degree of potential susceptibility to weather/climate events (ibid).

Extreme weather and climatic events can be classified into two categories according to their formation types. Accordingly, an extreme event occurs when a single meteorological variable, such as precipitation and wind speed, exceeds the fixed absolute values or percentile-based values or specific threshold frequency values. For example, heat and cold waves are generated due to the exceeding the threshold temperatures values defined for that region.

Certain extreme weather/climatic events occur when multiple weather and climatic events occur simultaneously and amplifying the impacts of these events. That is to say, if the precipitation falls below average in a certain period, it is not necessarily deemed as an extreme climate event, but the combination of insufficient precipitation and extreme temperatures can lead to drought, which is an extreme climate event.

***Figure 16:*** *Spatial distribution of the Mann-Kendall rank correlation coefficients over Turkey, which is calculated for annual numbers of frost day for the period 1949/1950 to 2009/2010. Here the downward triangles represent negative and plus represent positive trends, respectively (Erlat and Türkeş, 2012). Here the downward triangles represent negative and plus represent positive trends, respectively. Solid triangles and plus represent the statistically significant trends at the 5% level of significance, which are displayed in the legend.*

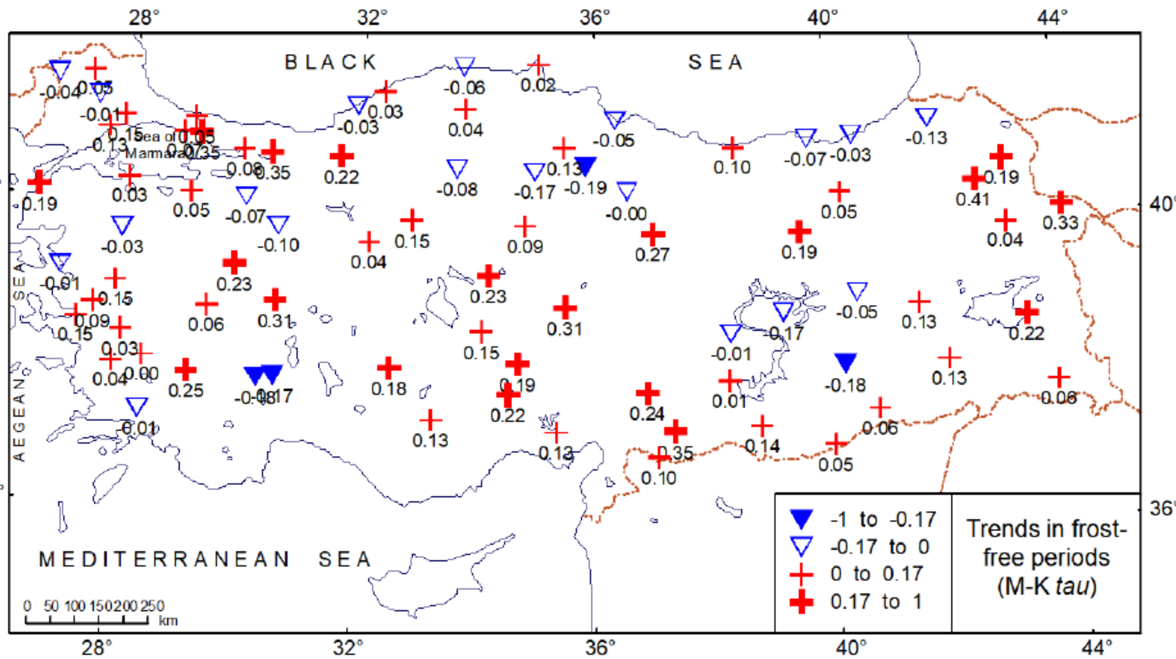



### 3.3.1 Changes and Trends in the Number of Annual Frost Days

In relation to the mentioned increase in the observed average, the maximum and minimum weather temperatures; magnitude, frequency and periods of extreme weather and climate events such as frosts, summer and tropical days, have altered.

For example, in Turkey, during the period between 1950 and 2010, the annual number of frost days showed a decreasing trend, particularly in stations located at Eastern Anatolia, Marmara and the Mediterranean coast; (Figure 16). The downward trend in stations such as Ardahan, Iğdır and Van has approached 4 days per decade.

***Figure 17:*** *Spatial distribution patterns of the Mann-Kendall rank correlation coefficients over Turkey, which is calculated in order to determine the long-term non-linear trends in the length of frost-free period (FFP) during the period od 1950-2013 (Erlat and Türkeş, 2016). Here the downward triangles represent negative (decreasing) and plus symbols represent positive (increasing) trends, respectively. Solid triangles and plus symbols represent the statistically significant trends at the 5% level of significance, which are displayed in the legend.*




## 3.3.2. Changes and Trends in the Length of Period with Frost Free Period

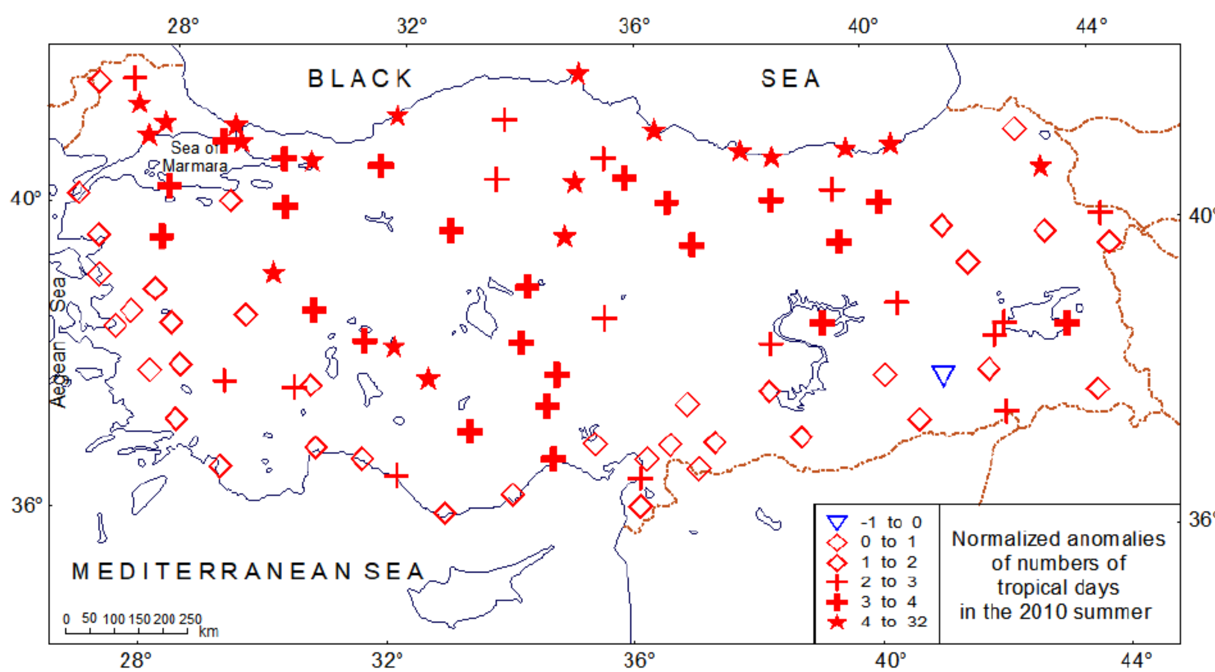
With the second half of the 20th century in Turkey, significant changes are observed in the beginning and end dates of frost events. In the 1950-2013 period, the first frost events of the autumn season shifted to a later date with a rate of 0.71 day/decade, and the last frost events of spring season tend to end on an earlier date so as to be 0.64 day/decade. As a natural result of mentioned notable changes, a statistically significant increase has been noted in the duration of observed the frost-free period (FFP) in a large part of Turkey (Figure 17).

## 3.3.3. Changes and Trends in the Number of Summer Days, Tropical Days and Tropical Nights

When the changes in the number of the summer (≥ 25 °C) and tropical (≥ 30 °C) days in the 1950-2010 period are examined, it is observed that there are spatial and temporal differences. The number of summer and tropical days demonstrated a slight decrease trend in the 1950-1975 period, with a certain increase trend in the values after 1975. The most striking year in Turkey in terms of number of summer and tropical days is 2010. In this year, in particular part of the North-East Anatolia (Figure 18), the number of summer and tropical days increased 3 standard deviation values compared to 1961-1990 average in almost half of the stations examined in Turkey.

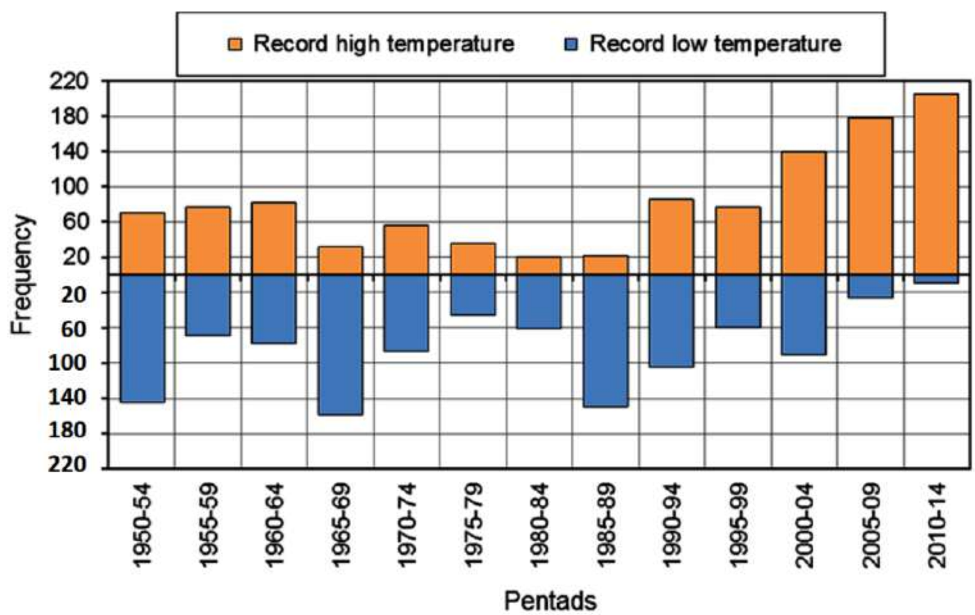
Another climate change indicator related to the issue is the "tropical night" climate indice. The tropical night is defined as a night when the lowest night (minimum) temperature observed at 2 meters ($T_{min}$) is higher than 20°C, and is analysed annually by means of a simple indice named as the *number of days when daily $T_{min}$ is higher than 20°C*. According to a new study which examined the changes and trends observed in the annual number of tropical nights recorded in 1950-2016 period at 92 climatology and meteorology stations (Erlat and Türkeş, 2017), there is statistically significant increasing trend in numbers of tropical night at the most of the stations (87 out of 92). When the changes between the years are taken into consideration, it is seen that the values are generally below the long term average in the 1950-1984 period and tend to decrease. In Turkey, the lowest number of annual tropical days during this period can be seen in 1976, 1968 and 1984. Compared to the average value, the number of tropical days per year showed a strong upward trend after 1985 with a continuous positive deviation (anomaly) and reached the highest numbers in 2010, 2012 and 2016. The observed upward trend is evident in coastal stations where the number of tropical nights is already high but weakened in Central and Eastern Anatolia stations where continentality prevails such that the number of tropical nights is lower and more variable (Erlat and Türkeş, 2017). These results indicate that the night temperature has risen rapidly in Turkey since the mid-1980s and the minimum temperature regime or its statistical distribution changed remarkably.

***Figure 18:*** *Spatial distributions of normalized anomalies in Turkey relative to the average and standard deviation of 1961-1990 normal period for the annual number of tropical-days in the year of 2010 (Erlat and Türkeş, 2013). The strongest and strong anomalies are respectively demonstrated with a bold plus and filled star symbol.*



Besides, it could be seen that, when the extreme weather conditions in Turkey are examined according to 27 climate indices recommended by WMO Climate Commission, a significant increase occurred in the number of summer days, warm days and nights and in the number of tropical nights; and a decrease in the number of days with frost, cold days and cold nights in 1960-2010 period. When the warm days and heatwaves are examined according to the 90th percentile regarding daily maximum temperatures in the summer season in Turkey, it is observed that the number of warm days and the duration of heatwaves increased in the west of Turkey between 1965-2006 and this increase became significant after 1998. Besides, it can be said that there is a strong relationship between the number of heatwaves and in the Mediterranean Sea surface temperatures and forest fires during the mentioned period.

***Figure 19:*** *Change in the annual number of record maximum and record minimum air temperatures observed in 81 stations in Turkey during 1950-201 period4, according to pentads (Türkeş and Erlat, 2018).*




### 3.3.4. Changes and Trends in Record Maximum and Record Minimum Air Temperatures

When we examine the temporal changes in the annual number of record maximum and minimum air temperatures recorded in the 1950-2014 period, it could be seen that the record minimum air temperature frequencies decreased from the 1950s up to now.

However, especially in the 2000s, there was an increasing trend in the record maximum air temperature frequency, and since 1950, half of the record maximum temperature events were recorded in the 2000-2014 period (Figure 19). The highest temperature values were recorded in 2000 and the lowest temperatures were recorded in 1950 in 81 stations used in the study. In recent years in which frequency of record maximum air temperatures has increased, mostly strengthened and long-circulating southern sector surface and boundary layer winds and southern sector warm air advection, which developed at a geopotential height of 850 hPa.

### 3.3.5. Changes and Trends in Dry Days Since Last Rain

In a study, which analysed the characteristics of atmosphere circulation in Europe and Mediterranean Basin which enable the formation of extreme precipitation in Turkey, the climatologic and meteorological properties of extreme daily precipitation in Turkey were examined using a criteria that is based on the highest 5% and 1% percentages of the daily total precipitation recorded in 70 stations of MGM in 1979-2011 period. The spatial distribution patterns of the highest 1% precipitation thresholds (mm) of daily precipitation data over Turkey are given in Figure 20. According to this distribution pattern, the daily highest 1% precipitation thresholds values (above 40 mm) were seen on the coastal belt of Turkey, namely the coastal belt and the mountainous areas beneath the South-western Anatolia, West Mediterranean and Eastern Black Sea. The lower values prevail in the interior and eastern regions, which are remote from the sea effect having continental properties.

***Figure 20:*** *Spatial distribution of the highest 1% daily precipitation thresholds (mm) according to total daily precipitation in Turkey (Lolis and Türkeş, 2016).*

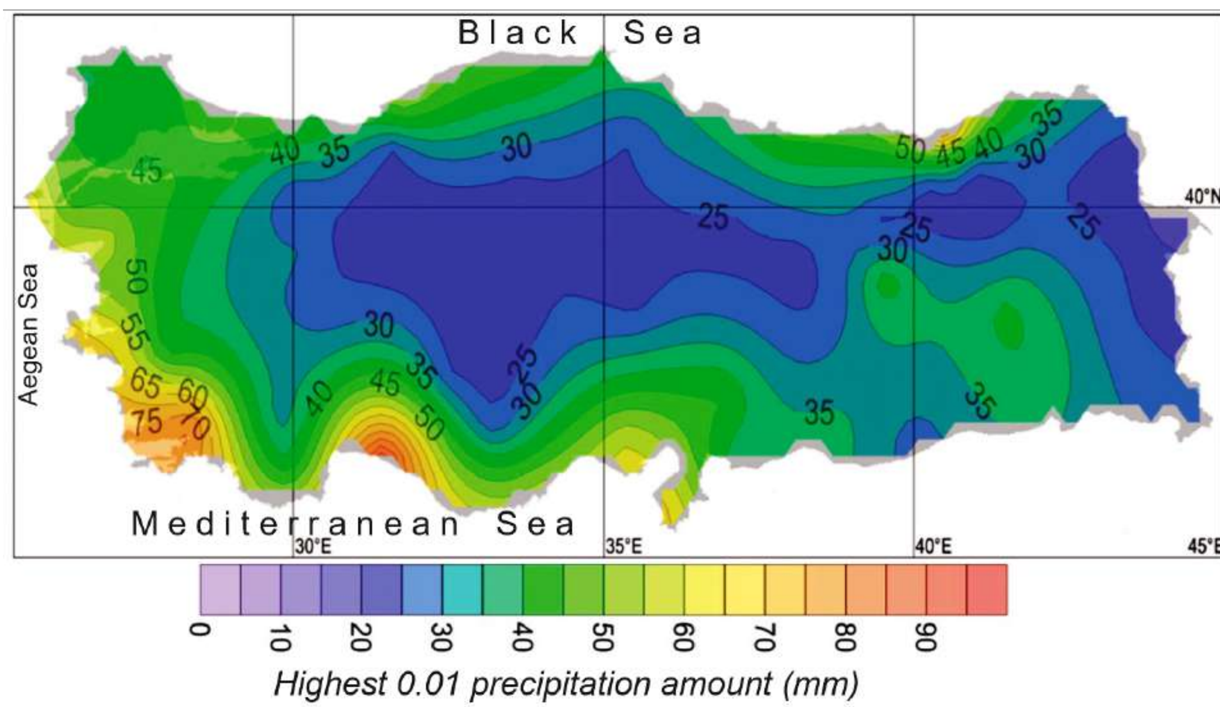
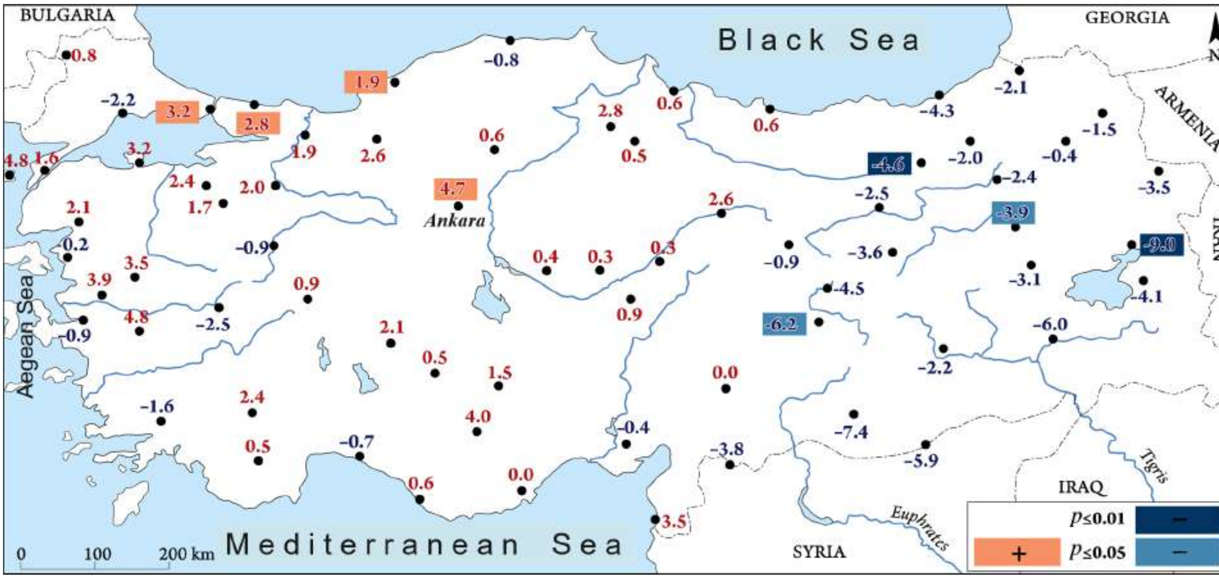


***Figure 21:*** *Linear trends of the longest DDSLR in each year. Only statistically significant trends are shaded (Kutiel and Türkeş, 2017)*




"*The dry days since last rain (DDSLR)*", which is a relatively new approach towards characterizing the dryness feature of a certain region, has been used in a new study for revealing the spatial, temporal, climatologic and statistical characteristics of droughts based on the 1970 – 2011 period daily precipitation data of MGM in Turkey. The *DDSLR* in a certain place can be evaluated using three different metrics; its severity, consistency and temporal uncertainty enabling to present intra- and inter-annual variations of the dryness. In the mentioned study, *DDSLR* is coupled with the Mediterranean Climate Index (MCI) approach, measuring the seasonality of rainfall. Overall, the three metrics of the *DDSLR* show their highest values in southern parts of Turkey along the Mediterranean and the borders with Syria and Iraq. These dryness indices in regions mentioned above are even larger than continental Central Anatolian Region of Turkey, which receives less annual rainfall. Areas, where dryness is at its minimum, are along the Black Sea coastal belt where a typical mid-latitude climate prevails with humid and mild conditions and rainy in all seasons. An increase in DDSLR, a measure of drought (intensification of drought), is more apparent in the western regions and in particular at north-western sections of Turkey.

### 3.3.6. Tornado Climatology of Turkey and Observed Changes

Sudden and severe weather events in recent years and months and severe thunderstorms, tornadoes, walnut-sized hail storms occurring in various parts of the Marmara Region (Istanbul, Çanakkale, Bandırma regions) and the coastal zone of the Mediterranean Region, especially in the Gulf of Antalya, and increased heavy number of precipitation events, reduced precipitation, and the causes of drought events in some regions and their links to global climate change and so on demonstrate that these are clear indications that we are facing many new and important issues.

***Figure 22:*** *The spatial distribution pattern of tornado events in Turkey. The map is prepared based on information and data observed and reported events or data gathered and verified by the Severe Weather Europe from various news sources for January 1, 2000, to February 19, 2019 period. (http://www.severe-weather.eu/).*


A severe thunderstorm with favourable surface and high atmospheric conditions can create very destructive and catastrophic weather conditions on land, especially when it occurs together with one or more tornadoes. The fact that tornadoes receive more interest in recent years in countries other than the United States of America (USA), including Turkey, which is related to the changes in frequency of occurrence and as well as increase in their magnitude and effects and the global climate change, and in particular closely linked increase in the surface (land and sea) and lower atmosphere (troposphere) temperatures and evaporation (in particular from seas and ocean). Theoretically and also according to some climate model studies, as a result of increased surface and lower atmospheric temperatures, evaporation and the water vapour content of the atmosphere (e.g., water vapour mixing ratio or specific humidity), convective instability or convection may increase (Türkeş, 2015a, 2015b). As a result of this, it is expected that more condensation latent heat will be released, and both magnitude and tornado formation capacities of the air mass thunderstorms (typical thunderstorms) and supercell storms will increase (Türkeş, 2015b, 2017). The change of frequencies of severe thunderstorm and tornado are predicted with less certainty since their formation is connected to various physical geographical elements and factors with various mechanisms.

As it could be clearly seen in our various previous works and explanations (e.g. Türkeş, 2015a, 2017; HürriyetDailyNews, 2017; Cengiz, 2019; etc.) and from the "Turkey Hurricane Climatology" map for South West Anatolia, West Mediterranean section and in particular Antalya Gulf, which we define as most common places of possible future tornadoes (a waterspout or a tornado), these places correspond to the geographical areas where hurricane is mostly observed (Figure 22). Certainly, there are some important physical, geographical and meteorological causes why tornadoes are more frequent and more effective in the Mediterranean Region, especially in the Gulf of Antalya. For a waterspout or a tornado to occur, there is need for the existence of a well-developed (very effective) thunderstorm, namely a cumulonimbus cloud (Cb)[19] or a compound Cb mass, or, need for presence of mesocyclone[20] in case of very strong tornadoes. Tornadoes can form ahead of cold front, in a downpour line or instability area + in very humid and unstable warm air. In the Gulf of Antalya and similar geographies, in addition, the sea effect and orographic lift closely control or trigger tornado formation[21] .

In recent years, especially in the last decade, various opinions and explanations are covered by written, verbal and social media claiming that "tornado cases are increasing in Turkey" after almost all significant tornado cases (which causes damage and loss of property and lives). Do these explanations have scientific evidence or support? To respond that question accurately at a certain level of confidence, it is necessary to examine the spatial and temporal changes in the tornado phenomena that take place in Turkey. The most appropriate approach for this is the statistical analysis of spatial and temporal changes in time series data related to the frequencies of tornado cases.

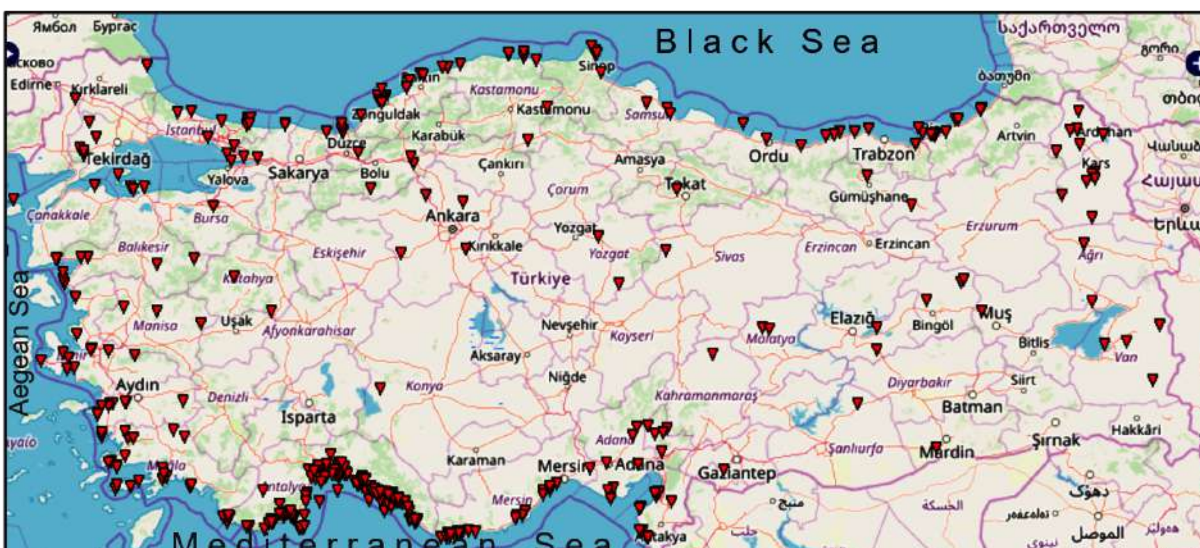
[19] These are the clouds with apparent vertical development in the atmosphere, comprising thick and wide cauliflower shape (cumulus) clusters, towers and columns, characterized mostly with cloudbursts and thundery showers (cloudbursts and/or hail or snow shower etc.) and associated with thunder, lightning and thunderbolt cases.

[20] It is a synoptic characteristic of cyclonic wind flow (counter clockwise direction in the north hemisphere), in other words of horizontal air movements, around a lower pressure center in meteorological weather maps.

[21] It is the meteorological and atmospheric phenomena that develop as the air masses are forced to elevate along mountain or mountain slopes that facing dominant air currents.

***Figure 23:*** *Prepared based on the information and data obtained and verified by the Severe Weather Europe (http://www.severe-weather.eu/).*


(a) Geographical distribution of the number of total tornado cases in Turkey during the 10-year period between 1 January 2000 (00:00 GMT) – 31 December 2009 (24:00 GMT).




(b) Geographical distribution of the number of tornado cases in Turkey during approximately a period of 9 years 20 days between 1 January 2010 (00:00 GMT) – 19 February 2019 (00:00 GMT)

Unfortunately, there is no tornado database yet in Turkey which could perform such type of detailed climatologic and statistical analysis. Under current conditions, such a fundamental analysis could only be done using the database of tornado events collected and verified by Severe Weather Europe center for all Mediterranean and European countries (Dotzek et al.2009). In an initial study that we have carried out relying on this database, initially a general comparison was made between the number of total tornado cases in Turkey in the 10-year period between 1 January 2000 (00:00 GMT) – 31 December 2009 (24:00 GMT) and the 9-year 20-days period between 1 January 2010 (00:00 GMT) – 19 February 2019 (00:00 GMT) (Figure 23). Figure 23 demonstrates that in the last past 10-year period, the number of observed tornadoes (January 2010-February 2019) is considerably higher than the number of tornadoes cases that occurred in the previous 10-year period (January 2000 – December 2009). In other words, there has been a significant increase in the frequency of the tornado cases in the last 10-year period compared to past years. When Figure 23 is examined, the existence of another striking situation appears. This is the fact that tornado cases started to appear in Eastern Black Sea and North East Anatolian region, where previously no tornado was recorded in the last 10-year period.

All of the above is the results of negative impacts of climate variability in all spatial and temporal scales and of human beings on global climate system, and also the result of negative actions of human on local and regional climates, geomorphology (slope, shape of slope, slope and soil stability, etc.), vegetation, effective rainfall (evaporation-transpiration, soil infiltration and surface flow balance), hydrology and hydrological network pattern (frequency, shape, relief energy, etc.).

Regardless of what the reason might be, today we see the results of global and regional climate changes (increase of surface and lower atmosphere temperatures and vaporization etc.) and experience the effects of extreme weather and climate events and disasters such as heavy flood, overflow, tornado, landslide, tropical and mid-latitude cyclonic[22] storms in connection with these.

Besides, numerous examples that we have analysed up to now demonstrate that climate change leads to changes in the frequency, magnitude, spatial distribution, duration and timing of extreme weather and climate events, with numerous impacts and negative results, both at the global and regional scale.

Model studies also show that in the future, our climate will likely be more variable in many parts of the world. The increase of variability means more and heavier precipitation, thunderstorm and tornado cases, more and heavier floods, overflow and mass movement, more and heavier heatwaves, drought and forest fires in many parts of Turkey, in particular in the Mediterranean Basin. To put it more clearly, it should be expected that in the future, we will have a more variable climate with stronger extremities having a more frequent and stronger deviation from climate “normal” or long-term averages in Turkey and its region.

[22] These are the strong and destructive spirals where the wind blows at a very high speed around a lower pressure center with very low central pressure value (very deep).

# 4. MODEL SIMULATION OF GLOBAL AND REGIONAL CLIMATE CHANGES

Rapidly developing climate models reproduce *observed continental scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20$^{th}$ century and the cooling immediately following large volcanic eruptions*. Human influence has been detected in warming of the atmosphere and the ocean, changes of the global water cycle, a decrease of snow and ice, global mean sea level rise, and changes in some climate extremes. It is *extremely likely* that human influence has been the leading cause of the observed warming since the mid-20$^{th}$ century (IPCC, 2013).

## 4.1. Global Climate Change Projections

According to IPCC (2013), the continuing release of greenhouse gas emissions will lead to more warming (Figure 24a) and changes in all elements of the climate system, primarily in vaporization and precipitation (Figure 16b). Mitigation of climate change will require important and continuous reduction of greenhouse emissions. The climate variability foreseen based on the new scenarios in IPCC 2013 report (Representative Concentration Pathway – RCP) looks similar to the one in the previous IPCC Report (2007) in terms of both patterns and size after taking into account scenario differences.

***Figure 24:*** *Expected model projection changes based on new IPCC RCP scenarios (RCP2.6 and RCP 8.5): (a) Change in average surface temperature (°C) in 2081–2100 compared 1986–2005 (b) Change in average precipitation (as %) in 2081–2100 compared 1986–2005 (IPCC, 2013)*

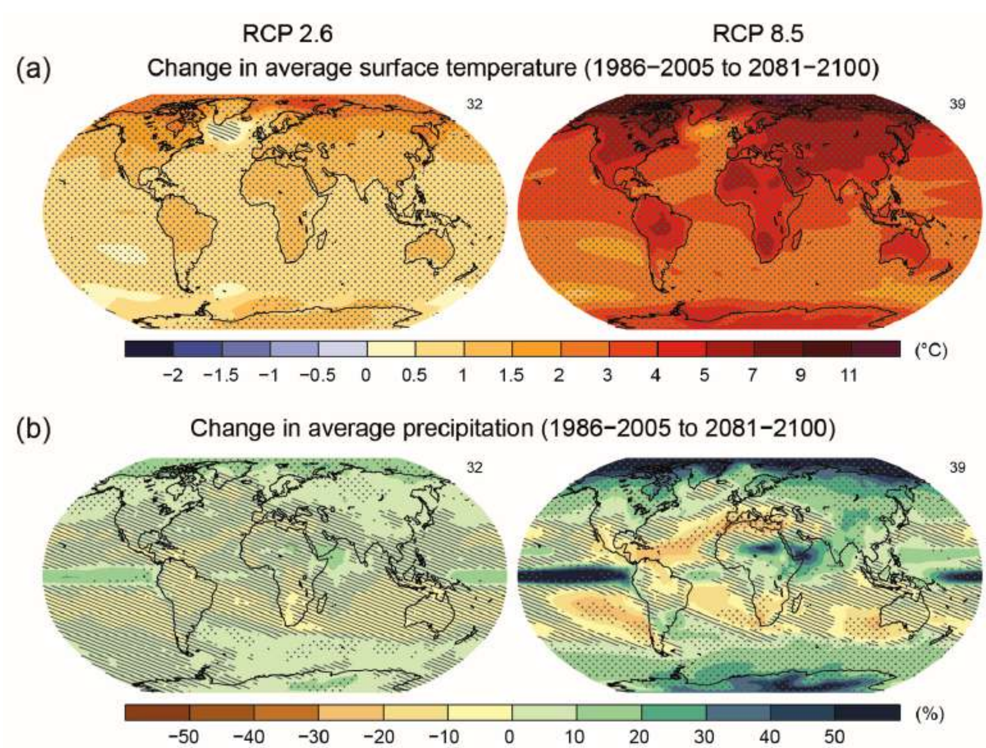
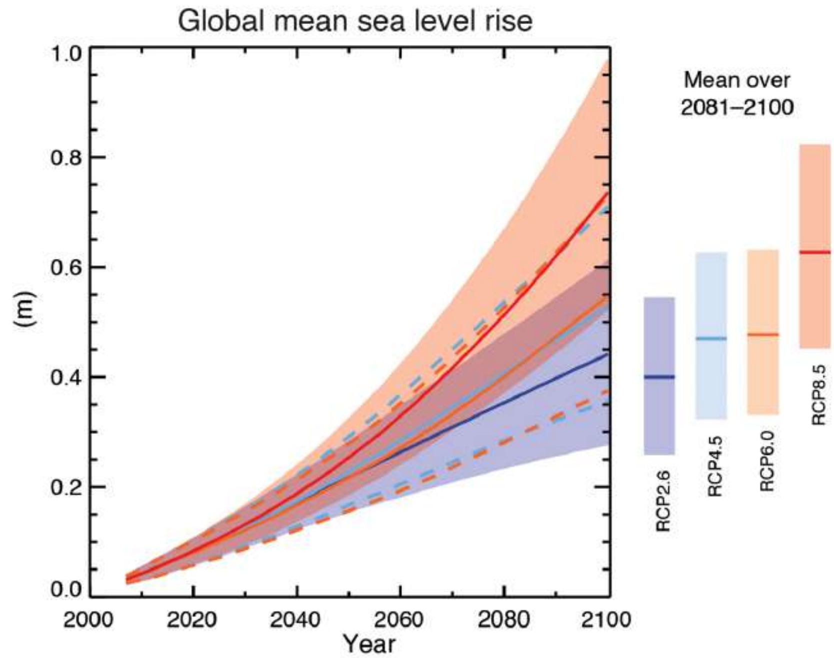


***Figure 25:*** *Projections of global mean sea level rise over the 21st century relative to 1986–2005 (IPCC, 2013). The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line.*

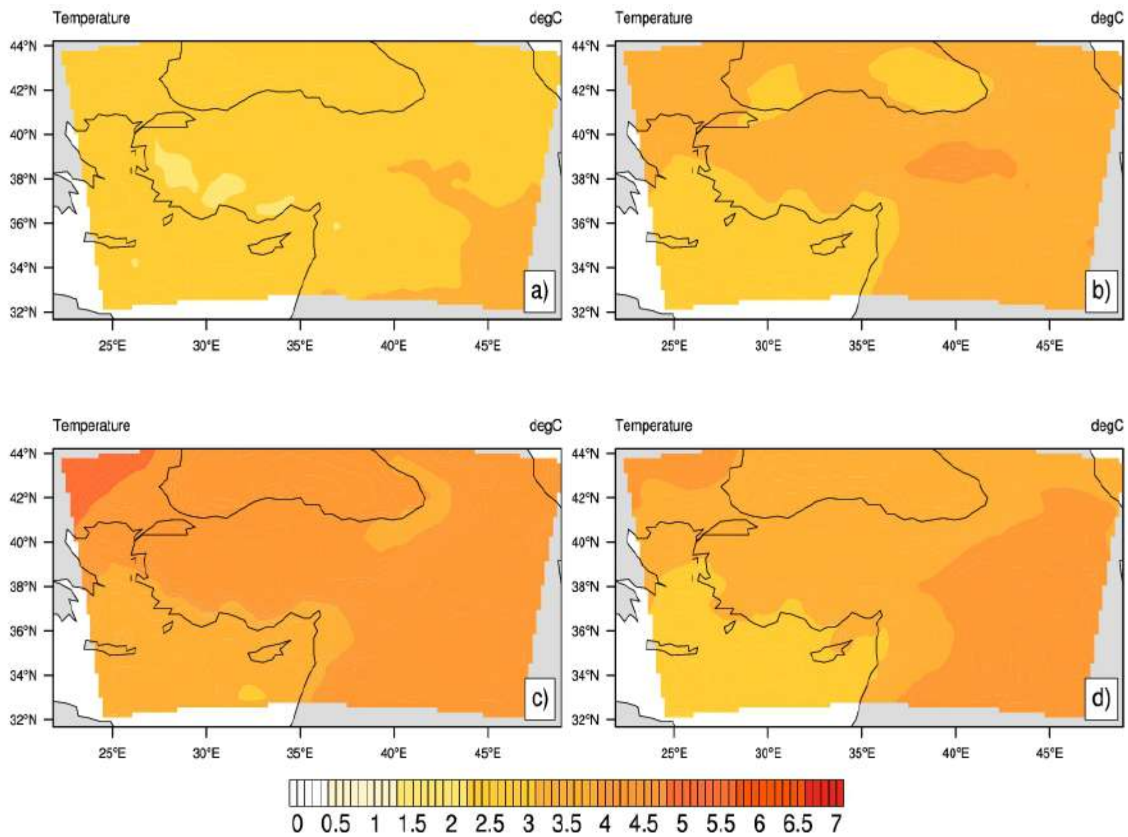



Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6 and it is *likely* to exceed 2°C according to two new scenarios (RCP6.0 and RCP8.5). Warming will continue beyond 2100. Warming and precipitation changes will continue to exhibit inter-annual-to-decadal variability and will not be regionally uniform (Figure 24a and 24b).

The global ocean will continue to warm during the 21st century. The heat will penetrate from the surface to the deep ocean and affect ocean circulation. It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global mean sea level will continue to rise during the 21st century (Figure 25). Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers/ice sheets. Moreover, climate change will affect carbon cycle processes in a way that will exacerbate the increase of $CO_2$ in the atmosphere. Further uptake of carbon by the ocean will increase ocean acidification.

Finally, I would like to remind you that many of the features and effects of global climate change will last for centuries, even if the release of $CO_2$ and other greenhouse gas emissions end. Furthermore, this fact shows that a significant climate change responsibility (e.g., the UN Kyoto Protocol and beyond), which will last for centuries, caused by past, present, and future emissions of human-made greenhouse gases, will persist.

***Figure 26:*** *Geographical distribution patterns of changes in projected mean air temperatures over Turkey and its nearby surroundings from the regional climate model RegCM, which is forced by the global climate model HadGEM2 with RCP4.5 scenario for the climatology of 2070–2100 future period with respect to the climatology of 1970–2000 reference period: (a) winter, (b) spring, (c) summer and (d) autumn seasons (Öztürk et al., 2014).*




## 4.2 Climate Change Projections for Turkey and Its Region

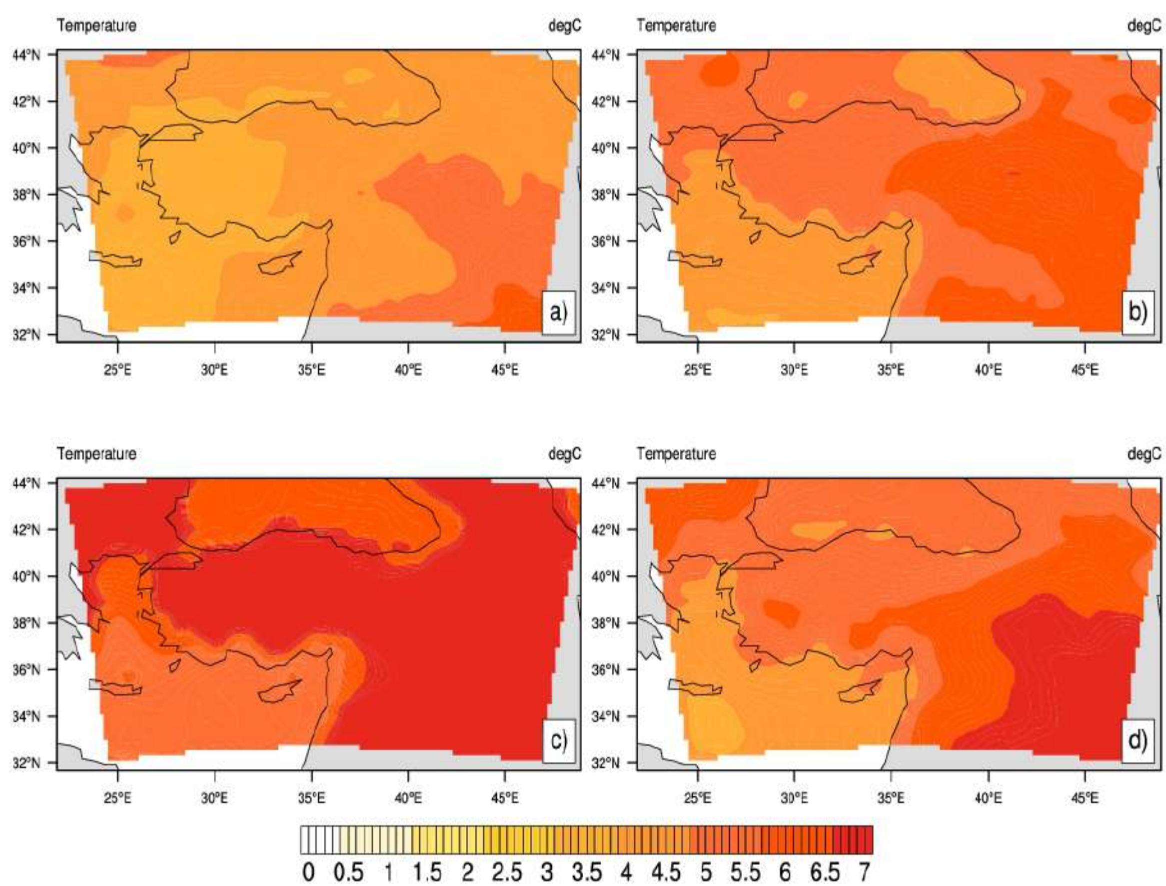
Studies related to climate change and variability observed in Turkey and regions surrounding it (in general Eastern Mediterranean Basin covering Balkans and Central-Eastern Region) and the simulations and projections of global and regional climate models demonstrate that significant climate changes occur in Turkey and Turkey will be negatively affected from the climate change together with many countries in the Mediterranean basin (IPCC, 2007, 2013; Trigo *et al.*, 2006; Türkeş, 1996, 1998, 1999, 2008b, 2012a and 2012b, 2013b and 2014a; Türkeş and Sümer, 2004; Türkeş and Tatlı, 2009; Türkeş et al., 2002; Türkeş et al., 2009a and 2009b; Türkeş *et al.*, 2011; Turp *et al.*, 2014; Öztürk *et al.*, 2015, vb.). Due to all these reasons, it is vitally important for predicting the future climate of Turkey in terms of preventing or minimizing the impacts of climate change, and of adaptation to it. Tatlı and Türkeş (2008, 2011), Önol and Semazzi (2009), Altınsoy et al. (2012), Önol and Unal (2014); Öztürk *et al.* (2012, 2013, 2015), Turp *et al.* (2014), Türkeş *et al.* (2011) and

Sen *et al.* (2012) could be given as examples of regional climate model studies ,which are scarce, towards demonstrating the future climate and climatic variabilities of Turkey.

This section is prepared based on a study by Öztürk et al. (2014)'s that predicts the changes in average temperature and precipitation climatology of Turkey for the period 2070-2100 with respect to the present climate (1970-2000) using regional climate model simulations.

In order to make the model projections of today's and future climate conditions, the International Centre for Theoretical Physics (ICTP) regional climate model RegCM4.3.5 was used. The HadGEM2 global climate model of Met Office Hadley Center was run with the downscaling method for Turkey and its surrounding area. In order to examine the changes which will occur in climate variables of Turkey in the future, outputs of RCP4.5 and RCP8.5 emission scenarios of global climate model were used.

***Figure 27:*** *Geographical distribution patterns of changes in projected mean air temperatures over Turkey and its nearby surroundings from the regional climate model RegCM, which is forced by the global climate model HadGEM2 with RCP8.5 scenario for the climatology of 2070–2100 future period with respect to the climatology of 1970–2000 reference period: (a) winter, (b) spring, (c) summer and (d) autumn seasons (Öztürk et al., 2014).*



According to the HadGEM2 climate model and RCP 4.5 emission scenario used, it is expected that the summer air temperatures in Turkey between the years 2070 – 2100 will increase by 4-6.5 °C according to 1970-2000 climatology. While increases in average air temperatures range around 3.5 °C for the winter season, these increases reach to 4-4.5 °C in the spring and autumn season (Figure 26). According to the HadGEM2 climate model and RCP 8.5 emission scenario used, it is expected that the projected air temperatures in summer in Turkey between years 2070-2100 will increase by 5.5-7 °C according to 1970-2000 climatology. It could be seen that the increase in average air temperature during winter is around 4.5 °C, and for spring and autumn seasons, it was between 5-7 °C, with an upward trend as one goes to east direction (Figure 27).

When the total precipitation projections are examined, in the simulation that using HadGEM2 climate model and RCP4.5 emission scenario, it could be seen that the change in precipitation in 2070-2100 years compared to 1970-2000 period climatology is expected to a decrease of 2 mm/day on the south of the country (negative deviation) and an increase of 1.6 mm/day (positive deviation) on the northeast. As opposed to this, it could be seen that the precipitation in summer season will change very little in the negative direction, and the projected trend will be weaker in spring and autumn compared to winter season (Figure 28).

***Figure 28:*** *Geographical distribution patterns of changes in projected total precipitation amounts over Turkey and its nearby surroundings from the regional climate model RegCM, which is forced by the global climate model HadGEM2 with RCP4.5 scenario for the climatology of 2070–2100 future period with respect to the climatology of 1970–2000 reference period: (a) winter, (b) spring, (c) summer and (d) autumn seasons (Öztürk et al., 2014).*

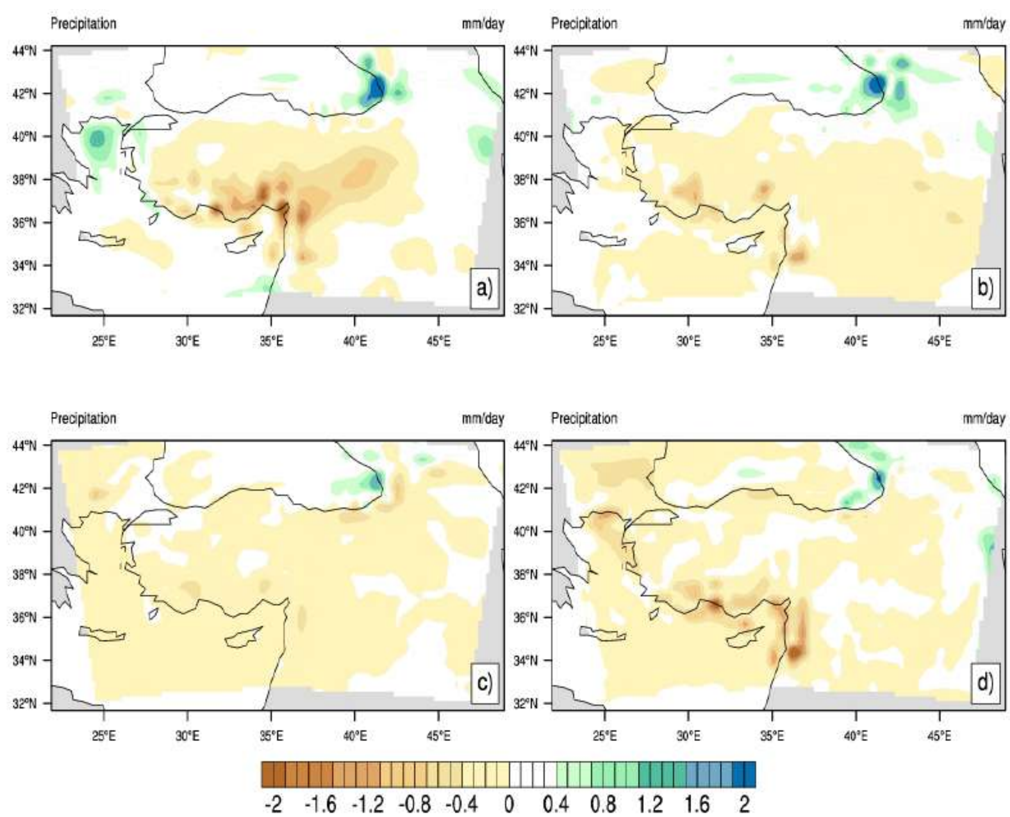
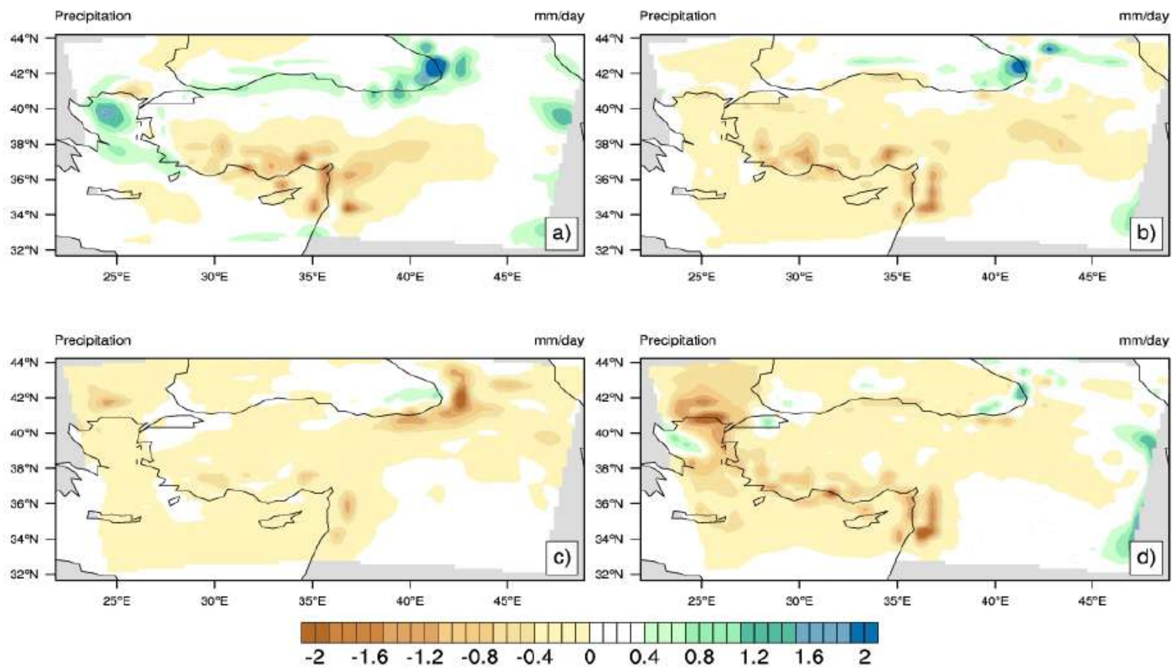


***Figure 29:*** *Geographical distribution patterns of changes in projected total precipitation amounts over Turkey and its nearby surroundings from the regional climate model RegCM, which is forced by the global climate model HadGEM2 with RCP8.5 scenario for the climatology of 2070–2100 future period with respect to the climatology of 1970–2000 reference period: (a) winter, (b) spring, (c) summer and (d) autumn seasons (Öztürk et al., 2014).*




The future projections based on simulation which is using the HadGEM2 climate model and RCP8.5 emission scenario show almost the same trend results as in the RCP4.5 emission scenario.

On the other hand, a decrease is expected in total precipitation on the south of the region, it is expected that the precipitation will increase in the northeast (Figure 29).

# 5. AN OVERVIEW OF INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE SPECIAL REPORT ON 1.5$^{O}$C GLOBAL WARMING AND MAINLINES OF THE REPORT

To give a brief explanation of the Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C Global Warming (IPCC SR 1.5°C), it deals with the effects of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (https://www.ipcc.ch/sr15/).

IPCC SR 1.5°C full report comprises 5 main sections. These are:

**1$^{st}$ Section -** Strengthening of global efforts towards anthropogenic global warming of 1.5°C;

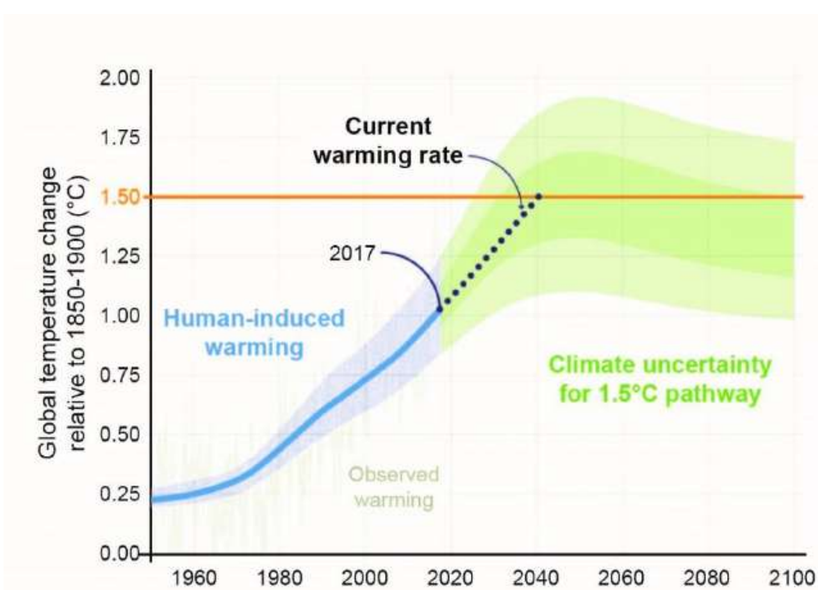
**2$^{nd}$ Section –** Understanding Global Warming of 1.5 °C; Mitigation pathways compatible with 1.5°C in the context of sustainable development;

**3$^{rd}$ SECTION:** Impacts of 1.5°C and 2°C Global warming on Natural and Human Systems and Related Risks;

**4$^{th}$ SECTION:** Emission Pathways and System Transitions Consistent with 1.5°C Global Warming; Strengthening the Global Response and its Implementations: Sectoral Evaluation and Pathways and Social and Economic Transition or Transformation Mechanisms and Pathways;

**5$^{th}$ SECTION:** Sustainable Development, Poverty Eradication and Reducing Inequalities.

***Figure 30:*** *Global temperature increase (°C) (relative to 1850-1900) (IPCC Special Report on 1.5 °C Global Warming, 2018; https://www.ipcc.ch/sr15/).*



## 5.1. Main Messages of Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5 °C Global Warming

To summarize, SR 1.5°C has evaluated the mentioned issue under 4 main headings: These are:

- What does Global Warming of 1.5°C Mean? Understanding Global Warming of 1.5°C;
- Projected Climate Change, Potential Impacts and Associated Risks
- Emission Pathways and System Transitions Consistent with 1.5°C
- Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty (Global Activity, Efforts and Initiatives)

### 5.1.1. Understanding Global Warming

Important points related to the issue have been summarized as follows in SR 1.5°C:

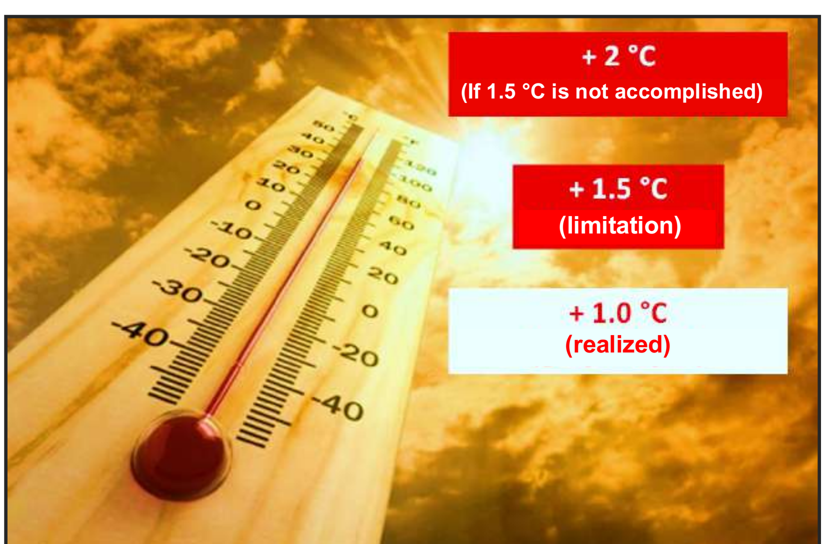
Human activities are estimated to have caused approximately 1.0 °C of global warming above pre-industrial levels (with a likely range of 0.8°C to 1.2°C) (Figure 30).

Global warming is likely to reach 1.5°C between 2030 and 2052 (Figure 30).

Warming from anthropogenic emissions from the pre-industrial period to the present will persist for a long time (centuries to millennia) and will continue to cause further long-term changes in the climate system (such as sea level rise, melting of glaciers).

Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C.

***Figure 31:*** *Understanding the 1.5°C Global Warming or Increased Temperature*



### 5.1.2. Projected Climate Changes, Potential Impacts and Associated Risks

The predicted risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options.

Perhaps the most important message of 1.5°C Global Warming Report – which we could say to be a surprise for the climate policy – is the discussion of two alternatives which are not distant from each other: 1.5°C and 2°C global warming targets (Figure 31).

When the governments adopted the 1.5°C target, which they had eagerly undertaken under the scope of Paris Agreement in December 2015 three years ago, they knew few things about which risks they prevent compared to a warming of 2°C, or they did not have clear information on what the paths are available towards the target.

One of the problems clarified by SR 1.5°C is that the global warming of 1.5°C will have significant impacts such that, for example, the ocean ecosystems will come to critical levels, and the tropical coral reefs are projected to decline by a further 70–90%. In case that the current greenhouse gas emission rates are maintained, the important risks in question are estimated to take place in 20-30 years.

Another important message of the report is that the impacts will be significantly higher compared to the scenarios of warming 2°C. The report has demonstrated that the global warming of 2°C compared to 1.5°C will have the following implication:

- By 2100, the global mean sea level rise is projected to be around 10 cm (0.1 m) lower with global warming of 1.5°C compared to 2°C. Sea level will continue to rise well beyond 2100, and the magnitude and rate of this rise depend on future emission pathways.
- A slower rate of sea level rise increases the chance of adaptation in the human and ecological systems of small islands
- Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems.
- Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels.
- Two folds of the land species will lose their geographical range, which is described climatically (biome, biotope).
- It is projected that there will be a loss of permafrost land more than 2 million $km^2$ within a timescale of more than a century.
- On average, twice as many people today (in some regions this rate will be higher) will suffer from climate change-induced water stress.
- Several hundred million more people will be exposed to climate-related risks and be more susceptible to poverty.

### 5.1.3. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

*For example, IPCC Special Report on 1.5°C Global Warming also gives hopeful news!*

Limiting the level of global warming to 1.5°C is still possible; however, this will not be easy.

According to this, it is necessary to net anthropogenic $CO_2$ emissions decline by about 45% from 2010 levels by 2030, reaching net zero around 2050.

This means that the $CO_2$ emissions arising from energy, industry, agriculture, housing and transport would be decreased by 75 – 90 % in 2050 compared to the year 2010.

Many 1.5°C pathways, which do not prolong the target to further date, cover carbon dioxide removal (CDR) technologies that could lead to other additional problems and their achievability is not easy.

These technologies include some technologies which are uncertain and have not yet become mature such as direct air capture and storage, enhanced weathering and ocean alkalinization.

Besides, afforestation and biotechnological practices also include irreversible land-use changes.

This could lead to significant impacts on agricultural and food systems, biodiversity, and other ecosystem services.

Pathways without CDR rely on scenarios that cover significant emission mitigations by means of widespread behavioral changes in such areas as transport and energy use.

***Figure 32:*** *Sustainable Development Targets*

### 5.1.4. Sustainable Development and Poverty Eradication

A more positive package message of the report is the synergies between sustainable development and limiting global warming at 1.5°C.

According to this, many pathways to reach 1.5°C will assist reaching Sustainable Development Goals (SDG) (Figure 32) in critical fields such as human health or decentralized renewable energy systems in order to access to energy. For example, in this scope, important and striking issues are handled in Section 5. These briefly include the followings:

- Poverty, equality or inequality in the world and reflection of a 1.5ºC warmer world on equality and inequality;
- Climate adaptation and sustainable development;
- E.g.: **SPECIAL SECTION: Ecosystem and Community-Based Practices in Drylands.**
- Climate mitigation and sustainable development: Sectors, food safety, hunger, water safety, air pollution and health, energy, houses, etc.
- Sustainable development pathways to 1.5°C global warming level;
- Conditions for achieving sustainable development, eradicating poverty, and reducing inequalities in 1.5°C Warmer World.

The report also demonstrates that the fighting against global warming decreases health risks arising from heatwaves, ozone pollution and, vector-borne diseases such as malaria triggered by climate change.

However, there are risks and imbalances such as increased energy use for desalination in water-scarce regions and negative impacts on fossil fuels driven economies.

The IPCC Special Report on 1.5°C Global Warming warns that negative effects of unequal or uneven distribution distributional impacts of climate change could be underestimated regarding the adverse effects climate mitigation such as requirements for international cooperation necessary for a managed transition and negative impacts of climate change or, the adverse impacts on poor and vulnerable communities.

# 6. DISCUSSION

Climate change is among the most discussed and emphasized global change issues at the intergovernmental level, with the most scientific research conducted. The predicted climate changes will have positive and negative impacts on water sources, agriculture, natural ecosystems, and human health. As the changes in climate grow, the dominance of negative effects increases. Socioeconomic sectors (e.g. agriculture, forestry, fishery, water resources and human settlement, etc.), land and water ecosystems and, human health which is very vital for the development and wealth of human beings are highly sensitive to weather and climate extremes and disasters, as well as, to the size and speed of climate changes.

According to the results of future climate model simulation studies, such as the new results of Öztürk *et al*. (2014 and 2015), the mean air temperatures could increase between 3 °C and 7 °C from the second half of the 21st century in Turkey. An increase in air temperatures is more in warmer seasons and the rate (speed) of increase gets stronger from the west of the country where the subtropical Mediterranean climate dominant to the east where continental climate prevails. According to regional climate change simulation, the precipitation amounts in Turkey could change between -0.8 mm/day and 1.2 mm/day. When the geographical patterns of projected amounts of precipitation are examined, it could be seen in general that - except the winter season- the western regions and southern parts will receive less precipitation over the year (drought) where Mediterranean precipitation regime prevails. On the other hand, it is expected in general that Black Sea Region where the precipitation regime is regular (rainy in all seasons) and a humid moderate mid-latitude climate prevails (in particular the Eastern Black Sea part), will receive more precipitation in winter and spring seasons and the northern part of Aegean Sea (North Aegean), which is cooler compared to Mediterranean climate and open to northern circulation and weather systems, will receive more precipitation during winter season compared to present values.

According to the results of the model, the projected changes do not vary according to the scenario but will be stronger in the cold period of the year.

Findings obtained from new climate model simulation studies (e.g., Öztürk *et al*., 2014 and 2015; Turp *et al.*, 2014) demonstrate that Turkey will be more affected by climate change due to the increasing air temperatures and decreasing precipitation amounts.

The Mediterranean coastal belt and south and central-south regions of Turkey, excluding Taurus mountains, where there is already high drought possibilities due to the less precipitation under current climate conditions with very hot and dry period (summer dryness that is effective from the end of spring to the middle of autumn), and prevailing precipitation variability between seasons and years and, will have a warmer and drier climate in the future. All these results also demonstrate that Turkey is very susceptible to the future human-induced climate change and their possible consequences and has a high level of vulnerability.

Taking the climate factors and the vegetation into account, the drylands of Turkey which have a tendency for desertification cover a significant part of continental inner and eastern regions and Southeast Anatolian Region. As regards a large part of Mediterranean and Aegean regions, taking into account the high-altitude and fragmented surface formations, non-agricultural and unsustainable use of agricultural areas for the last 40 years, attempts and legal regulations to abandon the agricultural and forestry land regimes which have high return values in terms of urban and tourism aspects, and other well-known natural and human-made factors such as industry, tourism and forest fires, the mentioned parts should be considered as semi-humid areas that could be more affected from future desertification processes. In addition to long-lasting and strong summer droughts and high air temperatures, observed change trends towards dry conditions in the precipitation and dryness index series that increase the desertification force of climate factors in Mediterranean and Aegean regions, also support this opinion.

The vulnerability of Turkey to earthquakes as well as drought, floods and overflows, storms and mass movements (landslide, landslip, mudflow, etc.) and its risks assessments are known more or less. The main problem in Turkey is both the lack of implementation/enforcement of the regulations and principles related to Disaster Risk Management and Mitigation of Disaster Impacts, and the lack of factual socioeconomic vulnerability data required for making accurate vulnerability/risk and adaptation analysis, or existing data is not usable/accessible in case of having incomplete/inadequate data. For example, even though the earthquake vulnerability of Turkey and its region and its earthquake geography and drought climatology and drought probabilities are very well known (in terms of being physically affected), the socioeconomic vulnerability data and information relying on real data is missing or not usable/ accessible. It is a big shortcoming, even a great problem. The important thing here is to be ready against all earthquakes and other disasters in accordance with the principles of Disaster Risk Management and Mitigation of Disaster Effects which relies on disaster monitoring, evaluation and prediction systems as well as well-prepared disaster vulnerability and risk analysis and reports, and to be prepared for earthquakes and all other disasters and to deal with disasters with a minimum loss of life and property and damage.

Another aspect of the issue is that in disasters that take place in large cities, almost no institution and organization tend to take any direct responsibility. Moreover, not any lesson is learned from natural/human borne combined disasters such as urban floods and overflows caused by heavy and long-lasting cloudbursts (human-induced urban disasters linked with wrong management, inaccurate planning and design), the engineering practices are very weak and wrong, the natural physical geography of the city and its regions, and in particular the natural topography, geomorphology, old or natural river network, flood plains and beds, prevailing and local winds, etc. are not being taken into account in the development plans of the cities. As a result, even moderate-heavy but slightly prolonged cloudbursts, together with the problems and deficiencies described above, and due most of the cities are covered with concrete and asphalt, develop into urban overflows and floods.

The drought, which is one of the results of the variability of climate is considered as extraordinary weather and climate condition or a natural disaster. Since the impact of drought on agriculture comprises the combination of very complex factors, it may not be possible to distinguish one from another.

Likewise, in relation to desertification which occurs as a result of coexistence of various complex factors and processes, including the degradation of lands and climate change, on arid, semi-arid or arid semi-humid lands; the role of natural (physical and geographical, hydrologic, biologic, ecologic and soil related) and man-made factors (incorrect land-use, land-use change, deforestation, excessive agricultural production, pasturing, water use and irrigation, agricultural pest control and fertilizer use) on desertification should be categorized and identified according to their function, significance and priority. For this, various "*decision making*" and/or priority setting methods such as Analytical Hierarchy Process (AHP), Environmental and Social Vulnerability and Risk Solutions, Topsis and Electre, could be implemented under a certain probability error or risk level.

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