Meteorology and Atmospheric Physics (2023) 135:40
https://doi.org/10.1007/s00703-023-00976-z

ORIGINAL PAPER

Temperature and precipitation extremes' variability in Turkey

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Received: 1 April 2022 / Accepted: 12 June 2023 / Published online: 28 June 2023

Abstract

Extreme weather events have become more frequent since the second half of the twentieth century. This study examines the long-term changes in temperature and precipitation extremes in two sequential periods over the period 1960–2019 using daily maximum, minimum, and mean temperatures and total precipitation for the four conventional seasons in Turkey. First, the Probability Density Function (PDF) for the mean temperature and precipitation are analyzed for the sequential periods. Second, extreme and relative value indices of the Expert Team on Climate Change Detection and Indices (ETCCDI) are used to evaluate changes in climate regions of Turkey for the considered period. A general upward trend in temperature indices is seen over the regions, but precipitation indices have more variable outcomes. The monthly minimum value of the daily maximum temperature (TXn) index has a 2 °C decades^{-1} increase, and except for five stations, there is a 1 °C decades^{-1} increase between the two sequential periods. While the annual total precipitation (RR ≥ 1 mm) (PRCPTOT) index has increased by 50 mm in the Black Sea, Continental-b and, Continental-c regions it has decreased in Mediterranean, Continental-a, and Transition regions. Similarly, very wet days (RR > 95th percentile) (R95p) and extremely wet days (RR > 99th percentile) (R99p) indices confirmed that the regions have not experienced an increase in extreme precipitation during the second half.

1 Introduction

Extreme events in the long term might have influences on society, economy, ecosystems, and human health; they direct to the environment include natural and human systems more than the average climatic conditions (Parmesan et al. 2000). The Intergovernmental Panel on Climate Change (IPCC) has concluded that most of the observed warming in global average surface temperatures has occurred since the mid-twentieth century, also it is likely the result of human activities (IPCC 2007). Recent data have shown that the global average temperature has increased by 0.85 °C over the last century. The updated IPCC Fifth Assessment Report reported that the global mean surface temperature has risen from 0.08 to 0.14 °C decade^{-1} between 1951 and 2012 (IPCC 2013a, b). Trenberth et al. (2007) showed that an average of 2 m temperature has risen by 0.8 °C since the late nineteenth century. Due to the increases in global and regional temperatures, it has been observed that research on climate change has increased over the last century (Fernández-Montes and Rodrigo 2011). There were studies regarding rising temperatures and changes, particularly in the last half-century (Khandekar et al. 2005).

Numerous studies have been conducted to show recent trends and variability in monthly regional climate data (Zhang et al. 2005; New et al. 2006; Anders et al. 2014; Caloiero 2017; Almazroui et al. 2021). The studies concerning the regions near Turkey provide a dramatic increase in temperature extremes in recent years for the Mediterranean region and the Middle East (Coumou and Robinson 2013), which have been accompanied by a long-term dry seasonal trend (Hoerling et al. 2012). An increasing trend has been identified in the process of storm surge events in the Mediterranean regions, and the significance of these trends is mainly related to the east coast of the Mediterranean basin (Cid et al. 2016).

Considering the dynamics of weather and climate, it would be unrealistic to define extreme events globally. Furthermore, the studies related to the extremes may have not combined to represent a universal form due to different approaches and methods (Bonsal et al. 2001). Concerning

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this matter, the joint scientist group of the World Meteorological Organization (WMO), the Commission for Climatology (CCl), and the Climate Variability and Predictability Expert Team (CLIVAR) have defined 27 indices to evaluate the climatic variability in Climate Change Detection, Monitoring, and Indices (ETCCDMI) (Zhang et al. 2005). A number of studies (Alexander et al. 2006; Zhang et al. 2011; Islam et al. 2015; Shawul and Chakma 2020) particularly in the past two decades due to climate change have been focused on extreme indices to evaluate precipitation and temperature variabilities. Most of the studies have used ETCCDI http://etccdi.pacificclimate.org/software.shtml, a joint WMO/CCl/CLIVAR/JCOMM Expert Team.

Many global and local studies have examined climate extremes over the past decade (Sillmann et al. 2013; Islam et al. 2015; Rashid et al. 2017; Ongoma et al. 2018; Abatan et al. 2018; Salvador and de Brito 2018; Saddique et al. 2020; Sippel et al. 2020). It is unfortunate that very few studies have been conducted on climate in Turkey using ETCCDI. In a detailed study of the Middle East in collaboration with researchers from 15 countries, Zhang et al. (2005) calculated 27 extreme temperature indices for the period 1950–2003 using daily data from 52 stations, including Turkey as well, but only nine stations. The Mediterranean region has been affected by both temperature and precipitation events owing to the complex topography and the variability of climate over subtropical latitudes (Abbasnia and Toros 2018). There has been substantial warming in the warm period compared to the cold period (Toros 2012a, b). Sensoy et al. (2013) conducted a research to analyze the trends of climate indices in Turkey by using data intervals between 1960 and 2010, and the results showed that the numbers of summer days, warm days, warm nights, and tropical nights have been increasing, while the number of frost days, cool days, and cool nights have been decreasing. Currently, heat waves are more common, especially in the Mediterranean region of Turkey, and a significant difference in the total precipitation was determined at the coastal stations compared to the inland stations (Sensoy and Demircan 2016). In this context, many research in Turkey have made some searches to analyze temperature trends in general (Tayanç et al. 1997; Karabulut et al. 2008; Doğan et al. 2015) however, these studies are not sufficient to evaluate the extreme temperature changes on various topographies at regional and to take action against to extremely severe events like forest fires in 2021 across Turkey.

This research is conducted based on observation data from 61 stations for the 1960–2019 period in Turkey. The main goal of this study is to investigate changes in temperature and precipitation with extreme climate indices for four conventional seasons in the identified climatological regions in Turkey. It provides comprehensive information about climate drivers' variability since it has a long period and many stations scattered throughout Turkey. Therefore, the consequences of this paper can be a reference and guide for urban planning, climate change adaptation, mitigation, and forest management studies.

2 Study area

Turkey is located between the temperate and subtropical zones and is surrounded by sea on three sides. The variety of topography and location of mountains lead to the emergence of different climate types (Atalay 1997). Considering climate classifications in the literature based on long-term precipitation and temperature data, seven climate zones are defined as Continental–a, Continental-b, Continental-c, Continental-d, Black Sea, Transition, and Mediterranean climate regions in Turkey, as illustrated in Fig. 1 (Erinç 1984). To define climate regions, some mathematical methods were applied to meteorological data in addition to assessing meteorological parameters. Their results confirm the seven climate regions with slight differences (Türkeş et al. 1995, 1996). In addition to identifying regions that can be considered similar to others, Ünal et al. (2003) argued that some provinces do not have the climate characteristics of their region, which causes false perceptions about climate conditions. Since the studies differ, Erinç's categorization was used as a reference in this study since it is widely accepted and provides a comparative analysis.

3 Data and methodology

In this paper, stations are covered which have maximum, minimum, mean temperature, and total precipitation for the 1960–2019 period. Hence, in total, 61 stations data are used, 8 stations in the Black Sea region, 6 stations in the Transition region, 14 stations in the Mediterranean region, 6 stations in the Continental-a region, 11 stations in the Continental-b region, 16 stations in the Continental-c region (Table 1). Note that the Continental- d region is not included in this study as a region since only Edirne station has data for the period. Since the station shows the same climatic characteristics as the Continental-c region and due to the fact that one station is not enough to represent a region, it has been categorized under the Continental-c region. Therefore, the six regions are investigated in this research.

In the twenty-first century, climate extremes are becoming more frequent, more intense, and more widespread (IPCC 2012). Therefore, investigating these phenomenon plays an important role in managing climate-related risks. The joint CCl/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) has defined a comprehensive set of climate indices including 27 extremes indices for

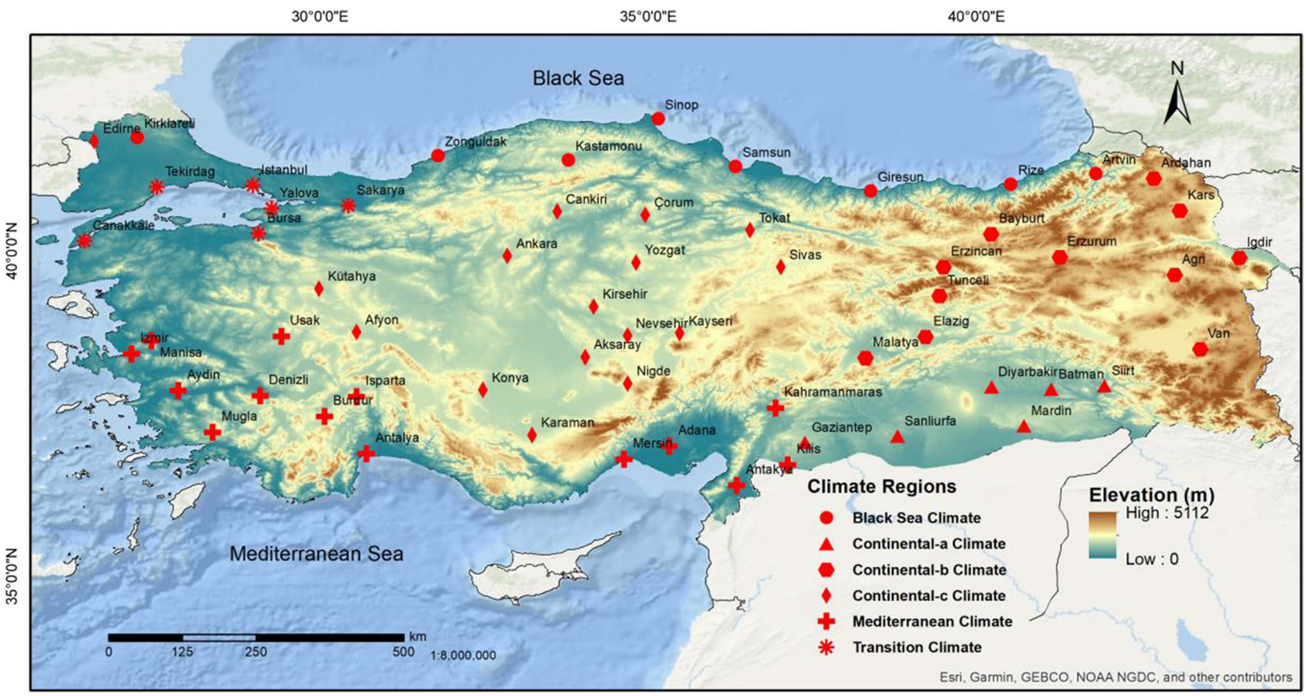

Fig. 1 Location map of stations and climate regions of Turkey

temperature and precipitation assessments. Particularly, the ETCCDI indices have provided reliable results of the daily variance of extreme events considering daily precipitation and temperature measurements (Zhang et al. 2011). In this paper, the R-based software package (RClimDex), which can be found on the ETCCDI (http://cccma.seos.uvic.ca/ETCCDI/list_27_indices.shtml), is utilized to compute the extreme indices concerning precipitation and temperature.

In this study, 11 out of 27 extreme climate indices are performed with temperature and precipitation values for the 1960–2019 period, as shown in Table 2. The indices are selected considering the nature of climate and the data availability. The extreme indices include the maximum of daily maximum (TXx) and maximum of daily minimum (TNx) temperatures, the minimum of daily maximum (TXn) and the minimum of daily minimum (TNn) temperatures are computed based on extremes of daily maximum and minimum temperatures. While, the relative indices including warm days (TX90p), warm nights (TN90p), cool days (TX10p), and cool nights (TN10p) are derived based on well-defined threshold values with respect to the daily maximum and minimum temperatures. For example, a day is considered a warm (cool) day when the daily maximum temperature exceeds the 90th percentile (10th percentile). Similar to the aforementioned temperature-based climate extreme indices, precipitation indices are also categorized as relative indices determined by very wet days (R95p) and extremely wet days (R99p).

As known, the main purpose of the Mann–Kendall (MK) trend test (Mann 1945; Kendall 1975) is to statistically determine if there is a general upward or downward trend of the variable considered time interval. This is a non-parametric (distribution-free) test and it is not expected that data would be normally distributed. Here, observed datasets are analyzed before the MK test to detect whether they need whitening procedures or not and it is not necessary since they turned out to be serially independent. In this study, using the MK test (Hussain and Mahmud 2019) indicated that the trend is statistically significant ($p < 0.05$) in mean temperature and total precipitation for the 1960–2019 period.

Homogeneous data sets are very important for detecting external effects on its nature. A study by Aguilar et al. (2003), when a long-term data set is homogeneous, indicates that the data set is only affected by atmospheric conditions. Many studies explain that inhomogeneity parameters are related to instrumentation, civilization, urbanization, and replacement or reconstruction of observation stations (Peterson et al. 1998; Türkeş et al. 2002; Sahin and Cigizoglu 2010). As mentioned above, expecting a homogenous behavior of long-term data from complex topography and getting bigger regions like Turkey, is almost impossible. In this study, Pettitt's Test (Pettitt 1979) and SNHT (Alexanderson 1986) are applied to see the critical points. Then Climatol (Guijarro 2021), available in the statistical package R, is used to homogenize the data series to calculate indices.

Table 1 List of used meteorological stations

ID	Station	WMO code	Latitude	Longitude	ID	Station	WMO code	Latitude	Longitude
1	Sinop	17026	42.0299	35.1545	32	Sanliurfa	17270	37.1608	38.7863
2	Samsun	17030	41.3441	36.2563	33	Diyarbakır	17280	37.8973	40.2027
3	Artvin	17045	41.1752	41.8187	34	Batman	17282	37.8636	41.1562
4	Giresun	17034	40.9227	38.3878	35	Ardahan	17046	41.1061	42.7055
5	Zonguldak	17022	41.4492	31.7779	36	Bayburt	17089	40.2547	40.2207
6	Rize	17040	41.0400	40.5013	37	Erzurum	17095	39.9058	41.2544
7	Kirklareli	17052	41.7382	27.2178	38	Agrı	17099	39.7253	43.0522
8	Kastamonu	17074	41.3710	33.7756	39	Igdır	17100	39.9227	44.0523
9	Istanbul	17636	40.9758	28.7865	40	Tunceli	17165	39.1058	39.5408
10	Çanakkale	17112	40.1410	26.3993	41	Van	17172	38.4693	43.3460
11	Bursa	17116	40.2308	29.0133	42	Elazıg	17202	38.6058	39.2973
12	Sakarya	17069	40.7676	30.3934	43	Erzincan	17094	39.7523	39.4868
13	Tekirdag	17056	40.9585	27.4965	44	Kars	17097	40.6042	43.1073
14	Yalova	17119	40.6603	29.2866	45	Malatya	17200	38.4343	38.0934
15	Manisa	17186	38.6153	27.4049	46	Cankiri	17080	40.6082	33.6102
16	Usak	17188	38.6712	29.4040	47	Corum	17084	40.5461	34.9362
17	Izmir	17220	38.3945	27.0821	48	Tokat	17086	40.3312	36.5577
18	Aydın	17234	37.8402	27.8379	49	Sivas	17090	39.7437	37.0020
19	Denizli	17237	37.7620	29.0921	50	Konya	17245	37.8687	32.4713
20	Isparta	17240	37.7848	30.5679	51	Aksaray	17192	38.3705	34.9987
21	Kilis	17262	36.7084	37.1120	52	Nigde	17250	37.9585	34.6795
22	Burdur	17238	37.7220	30.2940	53	Kırsehir	17160	39.1639	34.1560
23	Mugla	17292	37.2095	28.3668	54	Nevsehir	17193	38.6163	34.7025
24	Hatay	17370	36.5924	36.1582	55	Afyon	17190	38.7380	30.5604
25	Adana	17351	37.0041	35.3443	56	Edirne	17050	41.6767	26.5508
26	Mersin	17340	36.7808	34.6031	57	Ankara	17128	40.1240	32.9992
27	Antalya	17302	36.8851	30.6828	58	Yozgat	17140	39.8243	34.8159
28	Kahramanmaras	17255	37.5760	36.9150	59	Kutahya	17155	39.4171	29.9891
29	Siirt	17210	37.9319	41.9354	60	Kayseri	17196	38.6870	35.5
30	Gaziantep	17261	37.0585	37.3510	61	Karaman	17246	37.1932	33.2202
31	Mardin	17275	37.3103	40.7284					

Table 2 List of preferred ETCCDI indices

ID	Indices name	Definitions	Units
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days if TN < 10th percentile	%
TX10p	Cool days	Percentage of days if TX < 10th percentile	%
TN90p	Warm nights	Percentage of days if TN > 90th percentile	%
TX90p	Warm days	Percentage of days if TX > 90th percentile	%
R95p	Very wet days	Annual total PRCP if RR > 95th percentile	mm
R99p	Extremely wet days	Annual total PRCP if RR > 99th percentile	mm
PRCPTOT	Annual total wet day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm

4 Result and discussion

4.1 Evaluation of PDFs for temperature

Changes in daily mean temperature are assessed with PDFs for the aforementioned regions across Turkey in the two sequential periods (first half: 1960–1989; and second half: 1990–2019), as given in Fig. 3. The expected value of the daily average temperature is used as an evaluation metric to grab the changes between the two halves throughout winter, spring, summer, fall seasons, which covers DFJ, MAM, JJA, SON months, respectively. The PDF charts clearly illustrate that the Continental-a and the Continental-b regions have similar statistics. The daily mean temperature changes in Continental-a are 0.66 °C in the winter, 0.76 °C in the spring, 1.06 °C in the summer, and 0.7 °C in the fall. Similarly, the daily mean temperature changes are observed for the Continental-b region like 0.80 °C, 0.86 °C, 1.06 °C, and 0.59 °C in the seasons in the same order. Except for the Continental-a and Continental-b, other regions have significant changes in the peaks of temperature distribution and the standard deviation between the periods, especially during the summer and fall seasons. The slight changes for the Continental-a and the Continental-b regions can be related to the impact of geography, low population, and limited industrialization (Fig. 2).

The differences in daily mean temperature between the periods are 0.32 °C, 0.69 °C, 1.46 °C and 0.8 °C in the Continental-c; 0.10 °C, 0.83 °C, 1.56 °C, and 0.7 °C in the Transition region; 0.16 °C, 0.49 °C, 1.30 °C and 0.52 °C in Black Sea region; and 0.17 °C, 0.63 °C, 1.28 °C and 0.55 °C the Mediterranean region for the winter, spring, summer, and fall seasons, respectively. It is seen that a remarkable increase is detected during the summer months in comparison with other seasons. Also, the daily mean temperature increases 0.5 °C more on average in the second half in these four regions where metropolitan cities are placed i.e., Istanbul, Ankara, Izmir, and Antalya compared to Continental-a and Continental-b climate regions. In earlier studies, the summer temperature anomaly was found to become more prominent in metropolises because of the urban heat island (UHI) (Hung et al. 2006; Imhoff et al. 2010; Gao et al. 2019). A study by Founda et al. (2015), a gradual increase in daytime UHI intensity has been observed in the city of Athens since the mid-1980s which only increases in summer. According to Tayanç and Toros (1997), seasonal analyses of individual 21.00 h temperature series of four large Turkish cities suggested that regional warming is strongest in spring and weakest in autumn and winter. Due to urban warming, air conditioning energy consumption is also expected to increase during the summer due to urban warming. Regarding the relationship between energy consumption and meteorological parameters, there have been some studies to show a strong correlation between temperature and electricity consumption using principal component analysis and linear multiple regression (Doğan et al. 2016a, b).

To provide further knowledge, Table 3 shows that the highest temperature was measured in the period 1990–2019 for all regions and seasons. It is one of the prominent results of this research. As previous PDFs have revealed, the anomalies of the mean temperature are also higher in summer compared to the other seasons, with at least a 1 °C increase during the second half. On the other hand, the smallest changes with a 0.5 °C are observed in Continental-a and Continental-b regions during the winter season between the periods. It might be caused by the biggest dams of Turkey; Atatürk, Ilısu, Dicle and Keban dams which were built for energy and irrigation purposes launched after 1974 in Continental-a and Continental-b, respectively. Local studies explain the impacts of dams on the surrounding climate over the Southern and Eastern Anatolian regions (Şengün 2007; Ecer 2009; Kum 2016). Sarp and Erener (2017) detected that Atatürk Dam Lake increased the amount of humidity around using remote sensing techniques and satellite imagery for the period 1992–2016. A study by Arslan (2017) also showed that a small water body like Akkaya dam in Nigde (Continental-c climate) caused remarkable changes; increases in monthly total precipitation and monthly minimum temperature values and decreases in monthly maximum temperature, mean monthly temperature and mean monthly relative humidity values were observed for most of the months of the year.

4.2 Evaluation of temperature indices

A significant increase trend based on Mann–Kendall Test ($p < 0.001$) is observed in TX90p and TN90p indices in all seasons and regions; on the contrary to these, there is a significant decrease in TX10p and TN10p indices trend based on Mann–Kendall test ($p < 0.001$), shown in Figs. 3 and 4. The results of relative indices in this study also support the outputs of previous studies; with the warming of the climate, a downward trend in both the number of cold nights (TN10p) and the number of cold days (TX10p) is found for all seasons (Khan et al. 2020) and additionally, more than 95% of stations showed an increasing trend in warm days and nights at a 95% confidence interval (Saddique et al. 2020). Warm days have stronger trends during spring compared to winter and the majority of the stations show a significant increasing trend (Islam et al. 2015). TX90p and TN90p are shown to drastically increase in summer, especially since the early 2000s. A significant decrease in TX10p and TN10p days is determined since the end of the 1990s for the regions, which

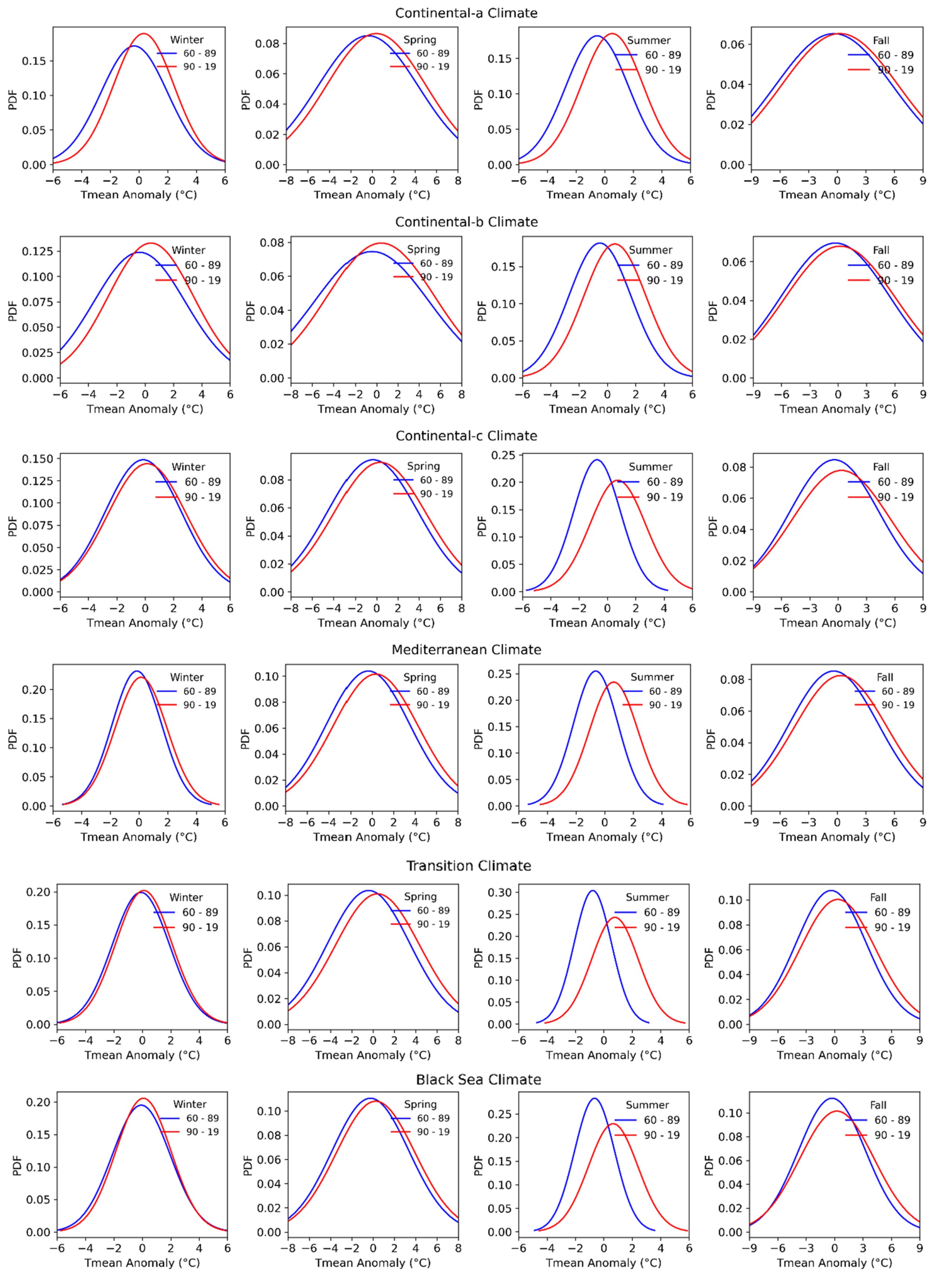

Fig. 2 PDFs of the mean temperature for the seasons in the climate regions over the first (1960–1989) and the second (1990–2019) half of the period

Table 3 The mean temperature based on climatic regions and seasons

Season climate	Periods	Winter (°C)	Spring (°C)	Summer (°C)	Fall (°C)
Continental-a	1960–1989	4.09	13.94	28.17	17.61
	1960–2019	4.42	14.32	28.70	17.96
	1990–2019	4.75	14.70	29.23	18.24
Continental-b	1960–1989	-4.25	7.68	20.39	10.60
	1960–2019	-3.84	8.11	20.91	10.90
	1990–2019	-3.44	8.54	21.45	11.12
Continental-c	1960–1989	0.95	10.16	20.36	11.87
	1960–2019	1.09	10.49	21.10	12.27
	1990–2019	1.27	10.82	21.83	12.62
Mediterranean	1960–1989	6.71	14.35	25.07	17.20
	1960–2019	6.86	14.70	25.70	17.57
	1990–2019	7.01	15.08	26.33	17.93
Transition	1960–1989	6.59	12.17	22.37	15.57
	1960–2019	6.69	12.59	23.15	15.94
	1990–2019	6.79	13.00	23.93	16.27
Black Sea	1960–1989	5.63	11.16	20.85	14.64
	1960–2019	5.71	11.40	21.50	14.91
	1990–2019	5.79	11.65	21.15	15.15

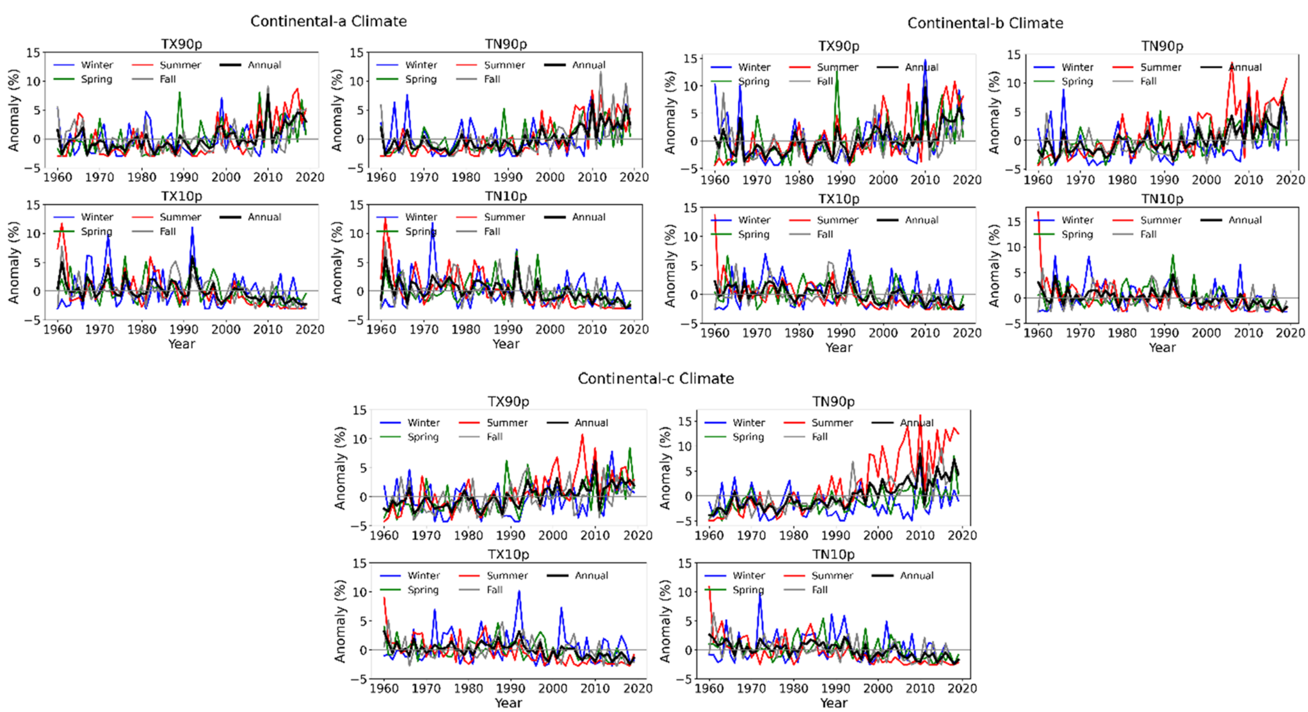

Fig. 3 Time series of Continental-a, Continental-b, and Continental-c climate indices (TX90p, TN90p, TX10p and TN10p) anomalies for the seasons over the 1960–2019 period. 0 point represents 10.1, 10.03, 10.2, 10.06, 0 point represents 14.72, 14.49, 8.61, 8.95, 0 point represents 14.24, 16.42, 9.16, 8.40, respectively for the regions

supports the extreme temperature increase in this period (Toros 2012a). It is seen that the indices for all regions show a common behavior and the 90s is a breaking point for the 1960–2019 period. After the 90s, TX90p and TN90p indices followed an upward trend, while TX10p, and TN10p followed a downward trend for the six regions. Additionally, the trend analysis of TX10p and TN10p indices for the period, the change in summer and winter seasons is remarkable. The

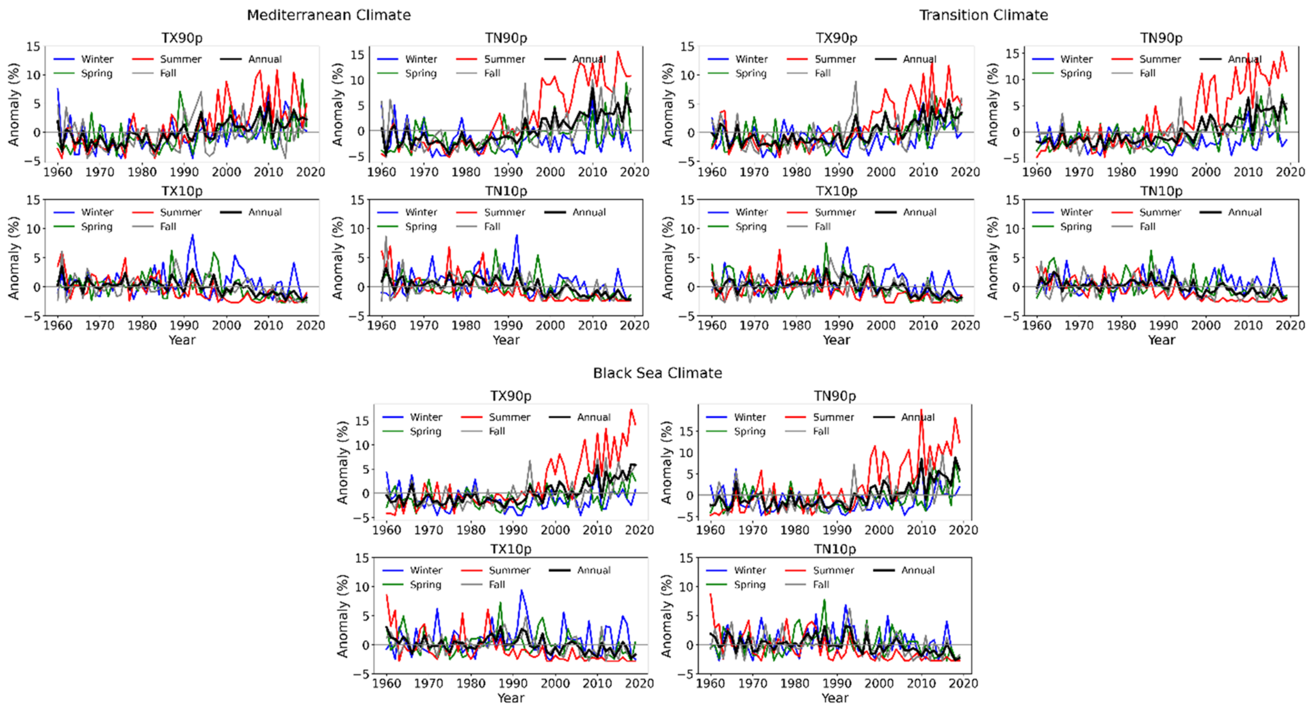

Fig. 4 Time series of Mediterranean, Transition, and Black Sea climate indices (TX90p, TN90p, TX10p and TN10p) anomalies for the seasons over the 1960–2019 period 0 points represents 15.08, 17.30, 8.89, 8.01, 0 represents 14.8, 16.14, 9.07, 8.40, 0 represent 15.06, 15.56, 9.36, 9.04, respectively for the regions

observed minimum temperatures reaching 20 days in TN10p index value has decreased to 4–5 days after the 2000s. Likewise, in a paper by Alexandre et al. (2006) analyzed ETCCDI indices for Turkey for the 1960–2003 period and reported that cool nights decreased since the 1960s, while warm nights increased.

IPCC reported that climate change started to affect the frequency, intensity, and duration of extreme climate events such as droughts, floods, and heatwaves globally at the end of the twentieth century which is likely to continue in the future, that each of the last three decades has been warmer than any of the previous decades (IPCC 2013a, b). There are coherent warming trends during summer over Turkey since 1960 and in the annual regional average mean, minimum and maximum temperature since the 1990s (Met Office et al. 2011). Similarly, the 61 stations show positive trends significant ($p < 0.05$) for TXx in the summer and fall seasons, and the stations by 28% show a positive trend with an increase between 1.5 and 2 °C in summer Fig. 5. In winter and spring except for only two stations for both (IDs 4–15 and IDs 2–4, respectively), showing a positive trend. The minimum value of daily maximum temperature (TXn) and the maximum value of daily minimum temperature (TNx) demonstrate a remarkable decreasing trend over the Continental-a region and east part of the Mediterranean region. A considerably increasing trend is found in the summer season for TXx, TXn, TNx, and TNn (°C decades^{-1}). Aside from climate change, anthropogenic impacts are also being investigated, which show that temperature patterns of seasonal means would likely be different without human-induced effects (Christidis et al. 2011). In a recent study conducted in Istanbul by Ünal et al. (2019), a consistent increasing trend of UHI was found on minimum temperatures regardless of the season, with the strongest signals in the summer and the weakest signals in the winter. Similarly, an increase in the majority of the stations for TNx and TNn (°C decades^{-1}) for all seasons is observed, and the increase in the summer season is also remarkable for the minimum temperatures between the two periods. In a study by Toros (2012a), proved that a significant warming trend in both annual minimum and annual maximum temperature values in Turkey, moreover the increasing trend in warm periods is stronger than in cold periods, especially at maximum temperatures.

4.3 Evaluation of PDFs for precipitation

The impact of climate change and human influence on precipitation variability over different regions have been investigated in numerous studies (Hulme et al. 1998; Fisher and Knutti 2015; Toros et al. 2017). Our results in the precipitation indices are consistent with previous studies for Turkey; a study by Met Office (2011) reported that changes

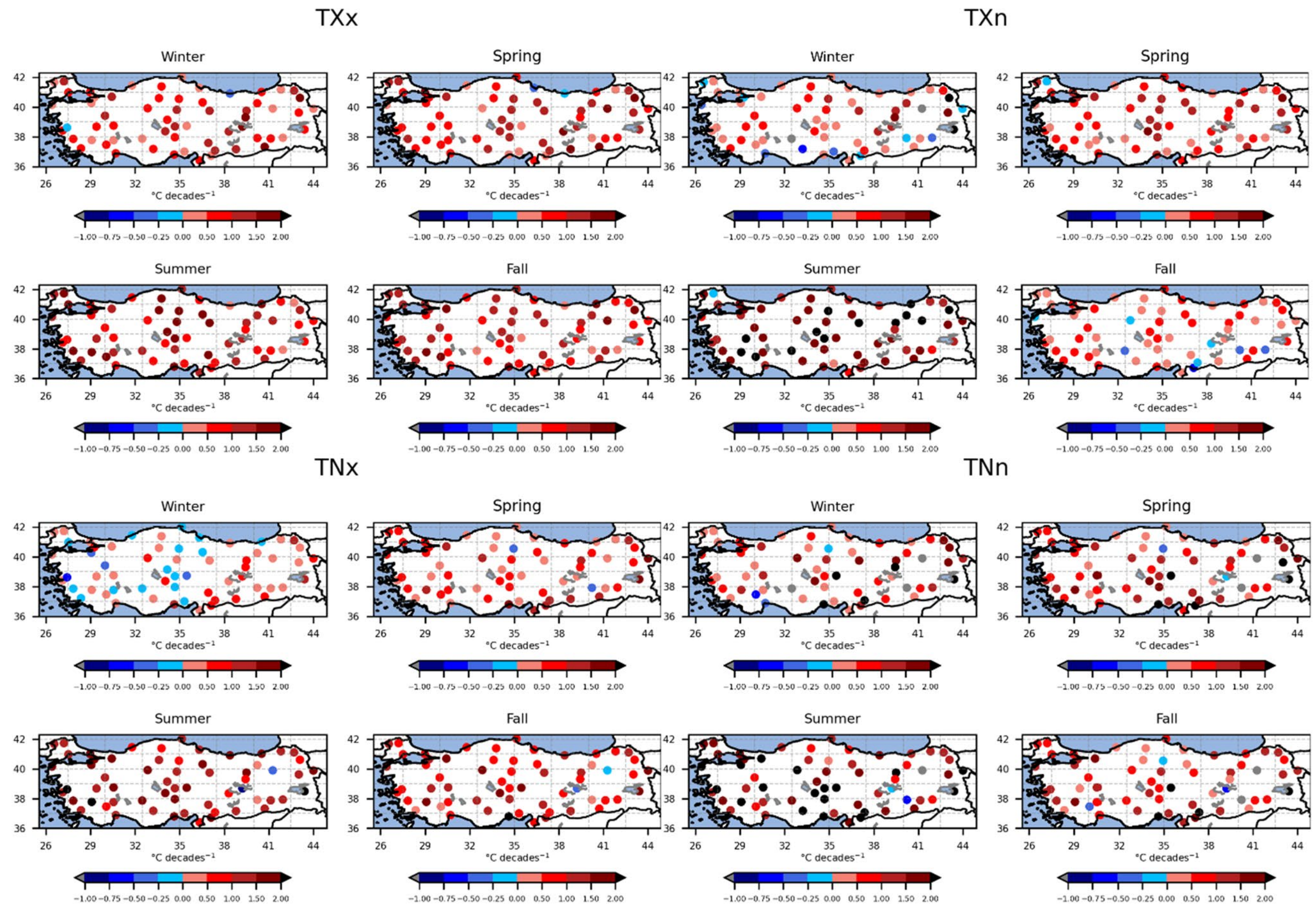

Fig. 5 Seasonal changes in TXx, TXn, TNx, and TNn indices between the first (1960–1989) and the second (1990–2019) half of the period

in precipitation are mixed with the increase in the west and increase in autumn in the north of Turkey, another study by UNFCCC (2007) examined using the Mann–Kendall test for the period 1951–2004 to evaluate seasonal precipitation trends show that there is a significant increase in the northern parts of Central Anatolia. Likewise, Sirdas (2002) claimed that the Black Sea region is the wettest part of Turkey, especially in the eastern part of the region has received 2400 mm annually, and the driest provinces are Konya, Diyarbakır, and Şanliurfa receiving less than 200 mm. Further information related to the precipitation, its correlation between other parameters like sunshine duration, evaporation, and its characteristics over Turkey were provided by the studies (Sahin and Sirdas 2002; Sirdas and Sahin 2008). The PDF is also performed to show total precipitation differences between the two sequential periods in the 1960–2019 period for the regions (Fig. 6), however, interpreting precipitation is quite different from mean temperature. While daily investigation on temperature has directed to coherent and interpretable outcomes, for precipitation, monthly, seasonal, annual evaluations have been needed for reasonable consequences to make inclusive for the regions. In this context, spatio-temporal studies are substantial to distinguish and assess the behavior of parameters (Kadıoglu 2000; Türkeş et al. 2009; Karabörk et al. 2003; Toros 2012b).

Numerous studies have investigated the key roles in the formation of general precipitation over Turkey in terms of synoptic-scale, general circulation pattern, and weather masses (Karaca et al. 2000; Ünal et al. 2012; Kömüşçü and Çelik 2013). Although the flash flood events that resulted in the losses of life and property in Turkey due to extreme precipitation events have become more severe and frequent (Baltacı 2017) in the last decade, only a limited number of studies have been conducted on the atmospheric conditions that cause extreme precipitation (Akkoyunlu et al. 2018, 2019). In this study, changes in the precipitation amounts are evaluated regionally, a serious variation is observed in the Continental-c, the Black Sea, and Transition Climate regions, compared to the first, there is an increase of 9 mm, 46 mm, and 8 mm in these regions, respectively. The previous studies have also observed an increasing trend in the number of consecutive dry days in the northern Marmara region (Abbasnia and Toros 2018), as well as an increasing trend in the number of extreme precipitation days in the

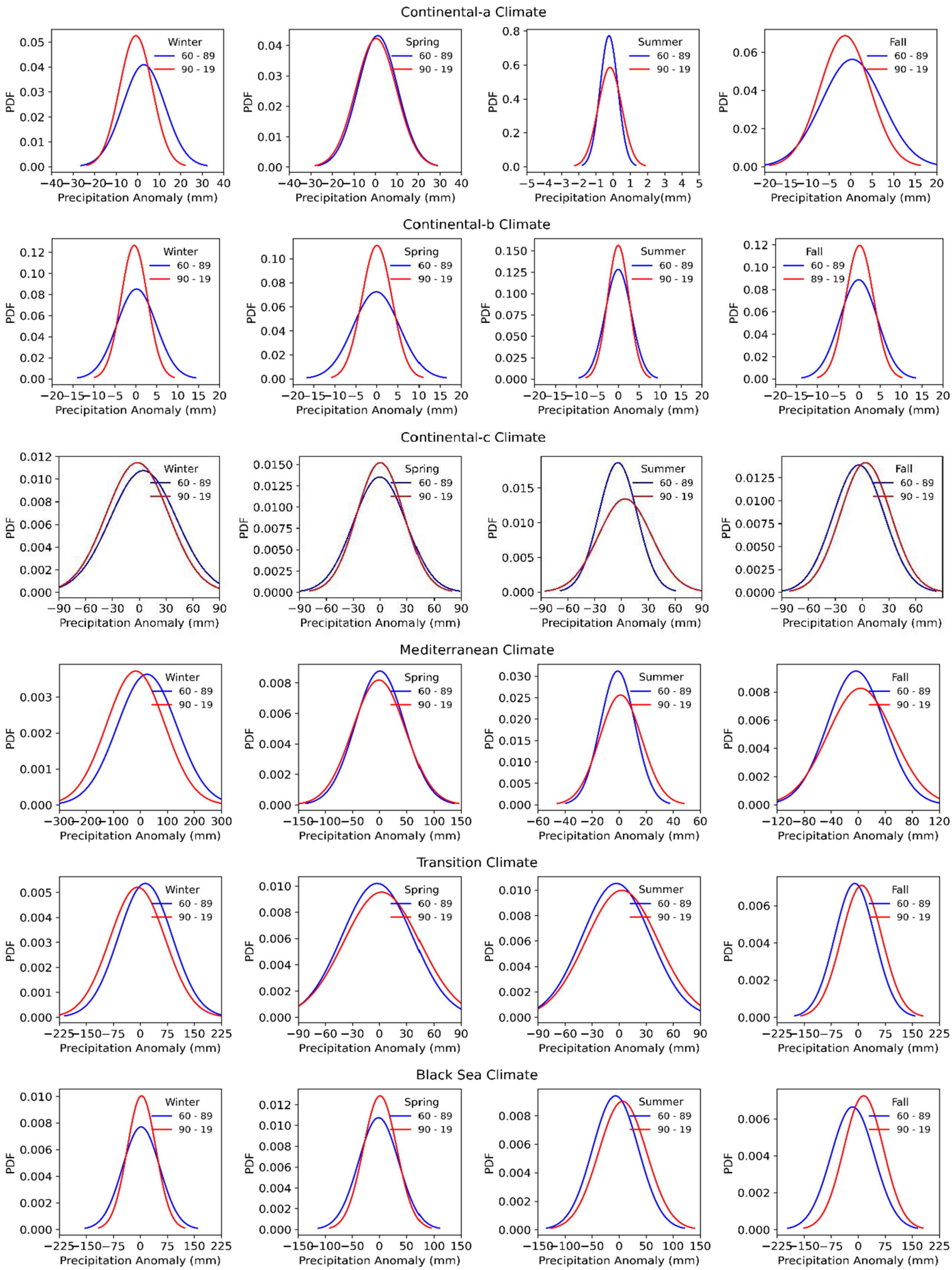

Fig. 6 PDFs of the total precipitation for the seasons in the climate regions over the first (1960–1989) and the second half (1990–2019) of the period

Mediterranean and Black Sea regions (Sensoy et al. 2013). Earlier studies showed that particularly the Black Sea region is prone to flash flood events due to extreme precipitations (Gürgen 2004; Sariş et al. 2010; Baltacı 2017). When the mean temperature (Table 3) and the average annual total precipitation (Table 4) are examined together for the regions, the period 1990–2019 has a critical situation in terms of extremes. Besides it has the highest mean temperature for all regions, it experienced the lowest total precipitation in winter seasons (only except for the Black Sea region) and the highest precipitation in summer seasons for all regions (Table 4). Hence the average annual total precipitation results also prove the flash floods which have happened over the last years around Turkey. If the changes are assessed seasonally a significant increase has been observed in the amount of precipitation in the summer and fall seasons. Considering the study conducted by Erinc, the ratio of precipitation occurring in the Continental-b, Black Sea, and Transition climate regions to the annual average rainfall of the regions in the summer months is 9.5%,19.4%, and 11.7%, respectively, while these rates are calculated as 16.8%, 19.8% and 13% for the last case in this study. The changes are notable both in proportion and in the quantity of the precipitation. It leads to a significant conclusion for assessing and updating the situation of precipitation trends over the six regions in Turkey. By examining the PDFs (Fig. 6) and the changes (Table 4) between the two sequential periods for average annual total precipitation, it is seen that the characteristic change in seasonal precipitation is more critical than the difference in the precipitation amount. PDFs show that characteristics of the precipitation trends have been varying and indicate that the frequency of sudden and heavy precipitation is increasing for the regions, especially in the Continental-b region. On the other hand, this could mean that more severe droughts are to be expected than in normal drought conditions.

4.4 Evaluation of precipitation indices

In addition to PDFs of total precipitation, extreme precipitation indices R95p, R99p, and PRCPTOT are calculated using daily precipitation data from 61 stations over Turkey for the 1960–2019 period. R95p, R99p, and PRCPTOT represent wet days, very wet days, and annual total precipitation, respectively. As expected, the wettest is the Black Sea climate region and according to the PRCPTOT, there has been a remarkable increase since the 90s in this region. While Continental Climate-b, Continental Climate-c, and the Black Sea climate have shown approximately 50 mm increase in PRCPTOT index, on the other hand, Continental-a, Transition, and Mediterranean region annual total precipitation values have decreased. As the extreme wet days have increased (decreased) over the period, the annual precipitation value has increased (decreased) so there might be a meaningful correlation between R99p and PRCPTOT. The Black Sea and Mediterranean regions are the clearest examples of that (Fig. 7). Since the very wet days' numbers can be commented on the tendency of extreme events, the indices resulting in this paper are proved by previous studies (Kömüşcü et al. 1998; Koç et al. 2020) about flash floods over Turkey particularly Black Sea climate region. Also, R95p, R99p, and PRCPTOT indices behaved quite

Table 4 The average annual total precipitation based on climatic regions and seasons

Season climate	Periods	Winter (mm)	Spring (mm)	Summer (mm)	Fall (mm)
Continental-a	1960–1989	253.12	203.64	6.30	101.63
	1960–2019	246.06	194.10	8.68	100.18
	1990–2019	241	184.55	11.07	98.73
Continental-b	1960–1989	115.48	170.37	77.57	100.60
	1960–2019	112.90	170.98	77.66	101.58
	1990–2019	112.35	171.59	77.75	102.56
Continental-c	1960–1989	138.33	143.45	55.65	85.04
	1960–2019	133.78	143.78	56.64	88.79
	1990–2019	131.65	144.10	63.62	92.54
Mediterranean	1960–1989	376.33	178.29	30.30	146.22
	1960–2019	351.60	177.40	31.37	143.52
	1990–2019	334.33	176.50	32.43	146.84
Transition	1960–1989	265.61	154.11	82.77	176.23
	1960–2019	251.60	156.62	85.84	185.93
	1990–2019	244.01	159.13	88.91	195.62
Black Sea	1960–1989	287.28	196.72	188.05	299.16
	1960–2019	284.76	198.08	194.63	314.30
	1990–2019	288.41	199.45	201.22	329.44

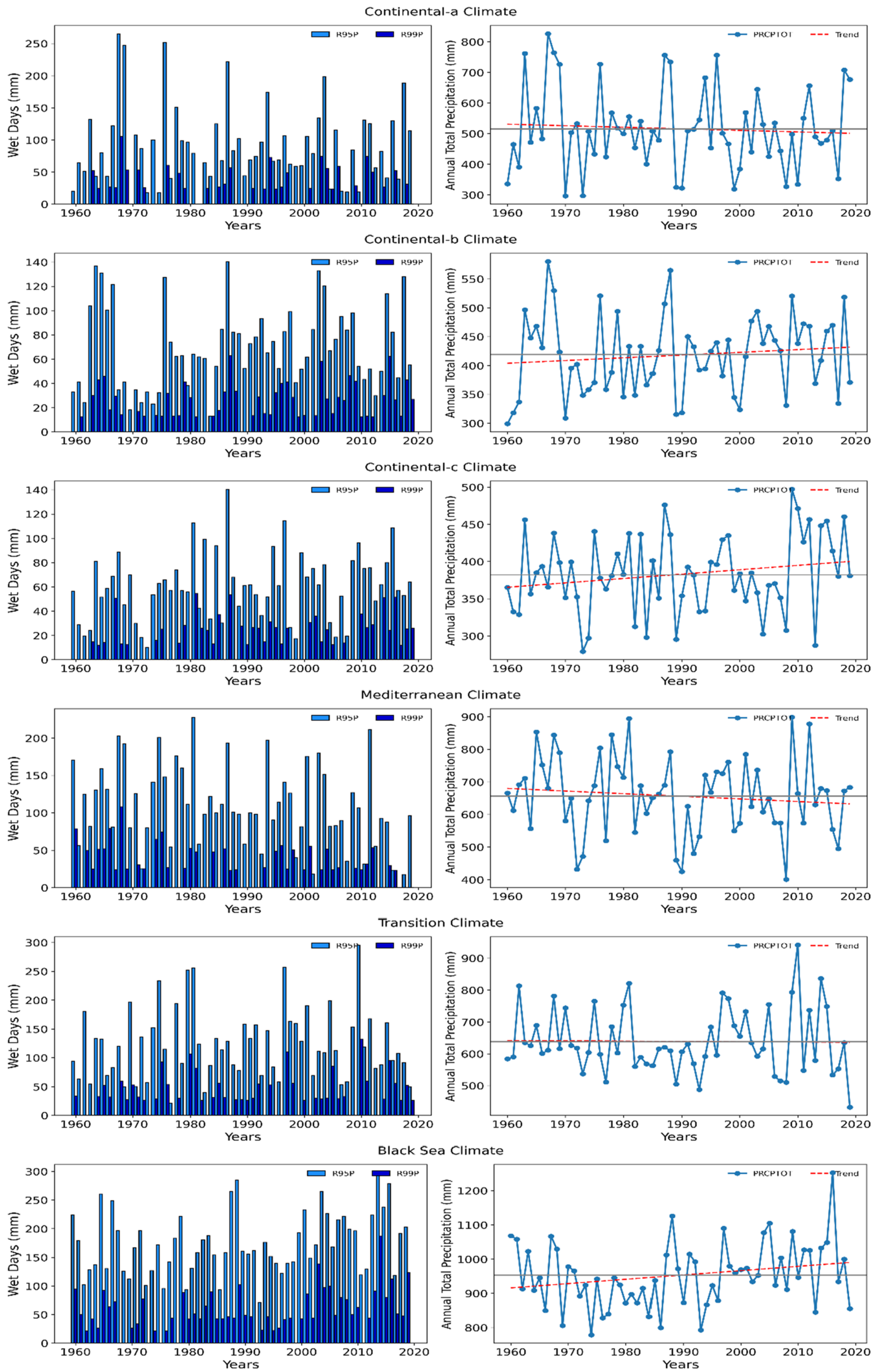

Fig. 7 Variability and trend of R95p, R99p and PRCPTOT indices of the regions for the 1960–2019 period

similarly in the Continental- a and the Continental-b regions; their annual precipitation averages got closer over time and are now around 450–550 mm (Fig. 7).

5 Conclusions

The PDF's results for the two sequential periods represent that there has been a distinct shift in the mean and median between the periods. The most dramatic change in average temperature occurs in the summer, with an increase of 1.56 °C. The extreme temperature indices also indicate that summer is the season with the most temperature changes, clearly shown by TXn and TNn indices. Multiple factors explain why the most obvious change is during the summer, including climate change, UHI, heatwaves, and convective activity. Furthermore, the majority of the stations have shown an increasing trend in maximum and minimum temperature values. An increase of more than 2 °C decades^{-1} was observed in TXn at 13 stations and in TNn at 17 stations. Also, except for five stations, TXn has increased by 1 °C in the second half.

According to seasonal trends in the relative indices, specifically after the 90s, TX90p and TN90p have gradually increased every season, while TX10p and TN10p have steadily decreased. In addition, the frequency of cool nights has decreased however the frequency of warm nights has increased in all seasons and regions. Therefore, the relative indices are in agreement with the results of the extreme indices. The dramatic increase in the relative indices after the 1990s can be explained by some local factors, such as UHI, topography, population, industrialization, and frequency of convective events. It might be worthwhile to further investigate the dramatic changes.

In contrast to the temperature indices, the precipitation indices do not have a common behavior across climate regions. Precipitation extreme indices indicate a decreasing trend in the amount of annual total precipitation in the Mediterranean, Continental-a, and Transition but indicate an increasing trend in the Black Sea, Continental-b, and Continental-c regions. The relationship between R99p and PRCPTOT is quite visible for all regions and there has been an increase in the frequency of extreme precipitation within total precipitation in the Black Sea, Continental-b, and Continental-c regions. Consequently, warning systems and precautions for upcoming flash floods are becoming even more crucial in Turkey. It is one of the important results of this study.

This paper represents the last circumstance of the precipitation and temperature studies by examining the long-term seasonal variability and the extreme indices in Turkey with 61 stations for the period 1960–2019 by evaluating the ETCCDI indices and it ıs revealed that Continental-a and Continental-b regions, it is obvious that the characteristics of the regions have changed over time and that they seem as a single integrated region at present. So redefining climate regions in Turkey is essential with comprehensive datasets.

Acknowledgements The authors would like to thank the Turkish State Meteorological Service for permission to use the meteorological data.

Author contributions NDC: data collection, visualization, methodology, investigation, writing—original draft. ADS: supervision, methodology, writing, review & editing-original draft.

Funding This study is partially supported by Istanbul Technical University-MDK-2019-42186 project.

Data availability The data that support the findings of this study are available from the Turkish State Meteorological Service but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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