Climatic Change (2009) 94:483–502
DOI 10.1007/s10584-008-9511-0

Climate change in Turkey for the last half century

Mete Tayanç · Ulaş İm · Murat Doğruel · Mehmet Karaca

Received: 23 January 2007 / Accepted: 2 September 2008 / Published online: 5 November 2008

Abstract Climate change and its urban-induced bias in selected Turkish cities is studied with a quality controlled temperature and precipitation data of Turkish stations in the period of 1950–2004. These stations are classified into two groups according to their populations; S1, including rural and suburban stations and S2, including large urban stations. Moving average signals, 365-day, and their digital low pass filtered versions are produced to eliminate the short term fluctuations and examine the possible trends or anomalies in climate data. Furthermore, 'relative difference' signals are introduced and applied to temperature and precipitation series to observe the actual local changes in the climate data independent from large-scale effects. Mann–Kendall test statistics are calculated for maximum, minimum, mean temperature and precipitation series and plotted on maps to determine any spatial trend patterns. Signal analysis show a cool period extending from early 1960s till 1993, generally with the lowest temperature values on 1992–1993 owing to the eruption of Mount Pinatubo. A last decade significant warming trend is observed in both of the series, S1 and S2, leading to 2000–2002 temperatures to be recorded as

M. Tayanç (✉)
Faculty of Engineering, Cyprus International University,
Haspolat, Nicosia, Mersin 10 Turkey
e-mail: mtayanc@ciu.edu.tr

U. İm
Institute of Environmental Sciences, Boğaziçi University,
Bebek, İstanbul, Turkey

M. Doğruel
Faculty of Engineering, Marmara University,
Kuyubası, İstanbul, Turkey
e-mail: dogruel@eng.marmara.edu.tr

M. Karaca
Institute of Eurasia Earth Sciences, İstanbul Technical University,
Maslak, Istanbul, Turkey

maximums in record history. The variability of urban precipitation series is generally larger than the rural ones, suggesting that urban stations can experience more frequent and severe droughts and floods. Though not significant, an increase in the urban precipitation compared to the rural one is also found. Spatial analysis resulted in significant warming in southern and southeastern parts of the country. Particularly, minimum temperature series show significant warming in almost all of the regions indicating the effect of urbanization. Significant decreases of precipitation amounts in the western parts of Turkey, such as Aegean and Trachea regions, are found. On the other hand, some Turkish northern stations show increases in precipitation of which some are significant.

1 Introduction

An increasing body of observations and analysis gives a collective picture of a warming world and other changes in the climate system. The global average surface temperature has increased over the 20th century by about 0.6°C. Climate change is threatening the food production, drinking water supplies and sustainable development throughout the world. Rising sea level, extreme weather events and desertification is just a few of the effects, especially threatening the millions of people living in less developed countries. Intergovernmental Panel on Climate Change report (IPCC 2001) expresses that global warming mainly caused by human activities is a reality and there are growing fears of feedbacks that will accelerate this warming. Climate change may have strong implications for political, economic, and social policy. Because climate change affects such a wide variety of disciplines and people, pursuing research in this field can generate important results that should be taken into account in strategic plans and policies.

Within the last several decades, the increasing efforts to gain insight into the man-made climatic changes have resulted in much work on temperature records, mainly in the developed countries. Previously, much work had focused on North American and European countries owing to the ready availability of abundant data. With the expansion of the global climatic datasets, a worldwide increase in the number of studies on climate variability has taken place, leading to a better understanding of the climate system (Jones and Mann 2004; Charlson and Wigley 1994; Kahya and Karabörk 2001; Kalaycı and Kahya 2006; Karabörk et al. 2005; Karaca et al. 1995, 2000; Karl et al. 1993; Kiehl et al. 2000; Nasrallah and Balling 1993; Tayanç and Toros 1997; Tayanç et al. 1997, 1998a, b; Wigley 2005; Ezber et al. 2006; WMO 1992).

This study is aiming to conduct a research on climate variability in Turkey via historical observation data extending back to 1950s, determine the time and place of significant changes in temperature and precipitation, and comment on the possible effects of the climate variability. In this respect, this work proposes to compile up-to-date and historical meteorological data, carry out nonparametric statistical tests and signal analysis, determine any climatic changes in Turkey, find the threatened regions, and look to the future for any climate change dangers.

In the following section we first classify the 52 meteorological stations having data in the period of 1950–2004 and explain the methods used in this study. In Section 3, we look forward to find any climatic changes in the minimum, mean, maximum temperature and precipitation series via trend and signal analysis, and comment on the findings and urbanization problems in Turkey.

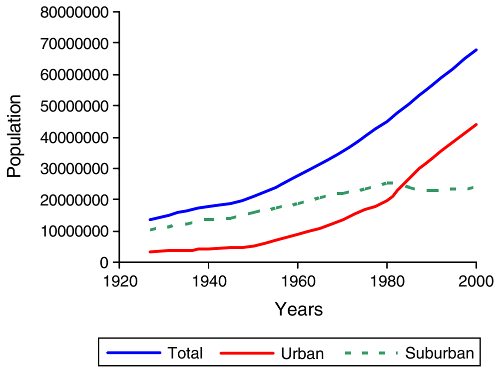
2 Study area and methods

The population of Turkey has grown almost 3.24 times between 1950 and 2000, from 20.947.188 to 67.803.927. As can be seen in Fig. 1, there is a sharp increase in early 1980s in urban share of this population. This increase of population in the favor of cities, has dramatic effects in the structure of land-use, convert the green areas to concrete buildings and this in turn may produce significant changes in the micro and meso-scale climatic conditions.

To investigate the changes in climatic variability in Turkey, maximum, minimum and average daily temperature and daily precipitation data, provided by the National Meteorology Service, from 52 meteorological stations in Turkey are analyzed for a 55-years time period, between 1950 and 2004 in the study. The spatial distribution of stations used in the study is presented in Fig. 2. The stations are classified into two groups according to the populations they represent; S1 for stations with a population below 100,000 and S2 for stations with a population higher than 100,000. Detailed information of these stations is provided in Table 1.

A computer code, which synchronizes the data by checking the missing dates or values, calculating the daily average for each day of a month throughout the whole available study period, and replacing the missing values with the calculated climatic averages, is developed for this purpose. The months having more than 15 missing days and the years having no data available are excluded from the datasets in order to obtain more reliable bases for the trend analysis. The homogeneity of each station for each parameter is checked by producing difference series with their neighboring stations. The stations that have one jump in the whole study period are corrected by either adding or subtracting a value, which is obtained by taking the difference between the averages before and after the jump. The program then calculates the monthly, seasonal and yearly averages for each station and for each temperature and precipitation series.

Fig. 1 Population variability in Turkey between 1927 and 2000



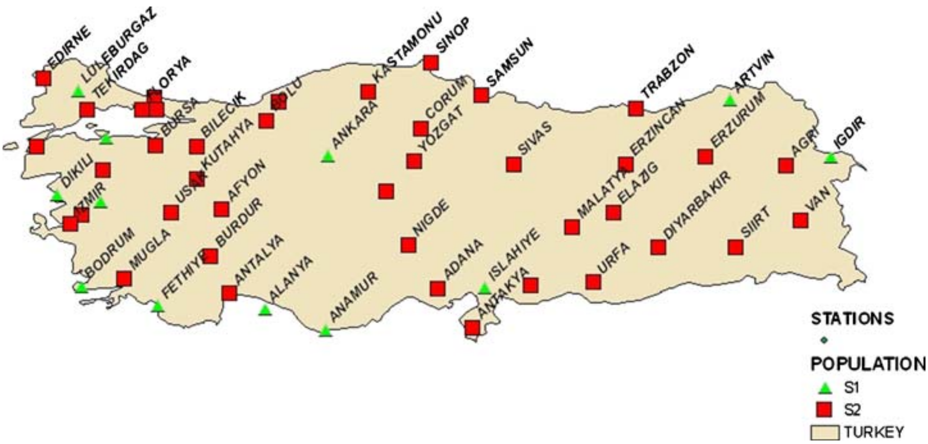


Fig. 2 The spatial distribution of the meteorological stations (*filled triangles* represents the stations characterized by populations up to 100,000 and *filled squares* above 100,000)

2.1 Mann–Kendall trend test

A non-parametric trend test, Mann–Kendall, is applied to temperature and precipitation series of all stations. If a Mann–Kendall statistic of a time series is higher than 1.96, there is a 95% significant increase in that particular time series. If the result is just the reverse, i.e. lower than −1.96, there is a 95% significantly decreasing trend in the series. The Mann–Kendall statistics are then plotted on a map in order to show the spatial distribution of both the significant and non-significant temperature and precipitation trends in Turkey. These plots are produced on monthly, seasonal and yearly basis to determine any significant climatic changes that might took place during the 55 years time period and to determine the critical periods that were mostly affected by the climate change. To prevent unrealistic spatial prediction, the boundaries of the domain are set to 25–48° E and 34.5–44° N.

2.2 Moving averaging and filtering the climate data

Let $S[n]$ show the signal representing one of the measured daily climate data considered. The day number, n, is determined by counting respectively for each day from an earlier reference day. Here the data represented by $S[n]$ may be minimum, average, or maximum temperatures, as well as precipitation series.

The 365-day running moving average, $S[n]$, of the original data can be calculated as,

$$S[n] = \frac{1}{365} \sum_{k=n-364}^{n} s[k].$$

This moving average signal, in idealized conditions, is expected to be as steady as possible because of the completion of the world's yearly cycle around the sun. The changes like increases, decreases, or oscillations in this average signal may clearly indicate the long term variances in the climate. The main difference in the definition

Table 1 WMO numbers, classifications, coordinates and 2000 populations of 52 stations

WMO no.	Station name	Latitude	Longitude	Altitude (m)	2000 Urban population	Class
17022	Zonguldak	41.45	31.80	137	250,282	S2
17026	Sinop	42.02	35.17	32	101,285	S2
17030	Samsun	41.28	36.30	4	635,254	S2
17037	Trabzon	41.00	39.72	30	478,954	S2
17045	Artvin	41.18	41.82	628	84,198	S1
17050	Edirne	41.67	26.57	51	230,908	S2
17056	Tekirdağ	40.98	27.55	4	395,377	S2
17059	Kumköy (Kilyos-İstanbul)	41.25	29.03	30	1,852	S1
17061	Sarıyer (Kireçburnu)	41.17	29.04	58	219,032	S2
17062	Göztepe (Kadıköy)	40.97	29.08	33	663,299	S2
17070	Bolu	40.73	31.52	742	142,685	S2
17074	Kastamonu	41.37	33.78	800	174,020	S2
17084	Çorum	40.55	34.95	776	311,897	S2
17090	Sivas	39.75	37.02	1285	421,804	S2
17094	Erzincan	39.75	39.50	1218	172,206	S2
17096	Erzurum	39.92	41.27	1869	560,551	S2
17099	Ağrı	39.72	43.05	1631	252,309	S2
17100	Iğdır	39.92	44.05	858	81,582	S1
17112	Çanakkale	40.15	26.42	6	215,571	S2
17114	Bandırma	40.35	27.97	58	97,419	S1
17116	Bursa	40.18	29.07	100	1,630,940	S2
17120	Bilecik	40.15	29.98	539	124,380	S2
17130	Ankara	39.95	32.88	891	3,540,522	S2
17140	Yozgat	39.82	34.80	1298	315,156	S2
17152	Balıkesir	39.63	27.88	102	577,595	S2
17155	Kütahya	39.42	29.97	969	318,869	S2
17160	Kırşehir	39.15	34.17	1007	147,412	S2
17172	Van	38.50	43.38	1671	446,976	S2
17180	Dikili (İzmir)	39.07	26.88	3	12,552	S1
17184	Akhisar (İzmir)	38.92	27.85	93	81,510	S1
17186	Manisa (İzmir)	38.62	27.43	71	714,760	S2
17188	Uşak	38.68	29.40	919	182,040	S2
17190	Afyon	38.75	30.53	1034	371,868	S2
17199	Malatya	38.35	38.32	898	499,713	S2
17201	Elazığ	38.67	39.23	991	364,274	S2
17210	Siirt	37.92	41.95	896	153,522	S2
17220	İzmir	38.43	27.17	25	2,732,669	S2
17238	Burdur	37.72	30.28	967	139,897	S2
17250	Niğde	37.97	34.68	1211	126,812	S2
17261	Gaziantep	37.07	37.38	855	1,009,126	S2
17270	Urfa	37.13	38.77	547	842,129	S2
17280	Diyarbakır	37.90	40.23	677	817,692	S2
17290	Bodrum	37.05	27.43	27	32,227	S1
17292	Muğla	37.22	28.37	646	268,341	S2

Table 1 (continued)

WMO no.	Station name	Latitude	Longitude	Altitude (m)	2000 Urban population	Class
17296	Fethiye	36.62	29.12	3	50,689	S1
17300	Antalya	36.88	30.70	51	936,240	S2
17310	Alanya	36.55	32.50	7	88,346	S1
17351	Adana	37.00	35.33	20	1,397,853	S2
17600	Lüleburgaz	41.40	27.35	46	79,002	S1
17636	Florya (Bakırköy)	40.98	28.75	36	208,398	S2
17964	Islahiye (Urfa)	37.01	36.38	513	38,770	S1
17984	Antakya (Hatay)	36.12	36.10	100	581,341	S2

given above is to calculate the last 365 day average value for *each day* in the working period. That is, $S[n]$ is found for each n in the range. Therefore the signal obtained this way carries much more resolution than, for example, a yearly based moving average signals.

As an example, the daily average temperatures of Bolu and the corresponding 365-day moving average (MA) signal is shown in Fig. 3a. The daily average temperature signal oscillates in larger amounts between the winter and the summer values, whereas the MA signal shows a relatively stable behavior as expected. In Fig. 3b, on the other hand, only the moving average signal is depicted to show the MA variations in detail.

To remove the shorter term fluctuations from the MA signal, and therefore to observe and detect the presence of longer term variations for trend analysis, a further smoothing can be performed by utilizing a digital low pass filter (LPF; Mitra 2001). For this, we consider a first order LPF with the following z-transform:

$$H(z) = \frac{1-a}{1-az^{-1}}$$

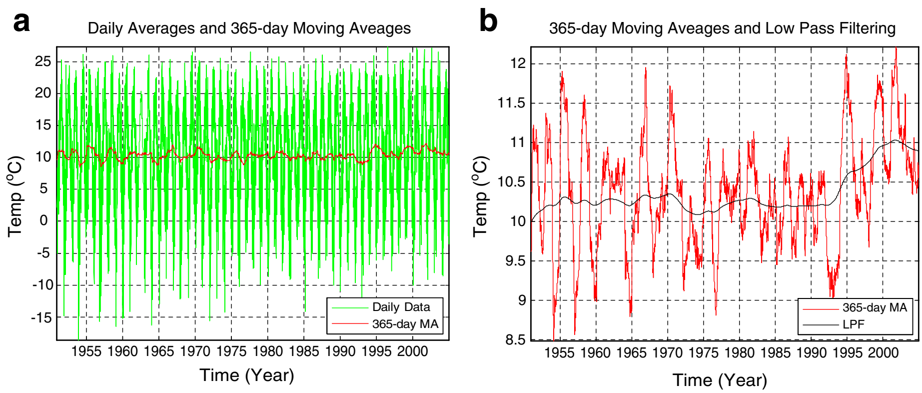


Fig. 3 **a** Daily average temperature variability of Bolu City and **b** its 365-day moving average and the low pass filtered signal

To eliminate the short term effects and exhibit the long term trends in the daily data, the parameter a is chosen to be 0.999, which produces a proper LPF with the time constant of approximately 3 years. To eliminate the phase shift errors, the data is processed by the filter above both forward and reverse directions. The start-up and ending transients are also minimized by matching initial conditions. The resulting filtered MA signal is also depicted in Fig. 3b. Here, an apparent rise in the temperature during the 1990s can be clearly observed, on the other hand, in the original daily data this rise is not very clearly detectable.

Relative differences When the 365-day MA variations, as defined in the previous section, are examined for various stations, it can be observed that very similar variations like sudden rises or drops are present in all stations due to the large-scale climatic effects. To eliminate those large-scale effects and expose the local changes or possible anomalies for a particular station or station groups in a region of concern, a Relative Difference (RD) signal is introduced as:

$$R[n] = S[n] - S_{\mathrm{T}}[n] - c,$$

where $S[n]$ is the MA signal of a particular station, or alternatively the average of the MA signals of a station group considered. $S_{\mathrm{T}}[n]$ is the average of MA signals of all the stations considered (in this case all the stations given in Table 1 for Turkey). $S_{\mathrm{T}}[n]$, as an average of all stations, represents the large-scale effects in the regional climate data, and when the difference is taken as shown in the equation, these large-scale effects are mostly eliminated from the local MA signal. A constant number, c, is also subtracted from this signal in such a way that the total mean value of the relative difference signal, $R[n]$, in the considered time range becomes zero. Therefore only the local relative difference signal almost free from large-scale changes is obtained for the station(s) considered. Due to various short term variations present in all stations, the RD signal obtained this way may have an additional high frequency noise component that does not actually carry any valuable information. To eliminate this noise and obtain the actual long term trends or possible anomalies, again the same LPF as defined in the section above can be utilized for the RD signals (LPFRD).

3 Results

3.1 Signal analysis

Low pass filtered moving average (LPFMA) curves for the daily mean temperatures of various cities are produced and presented in Fig. 4. In the natural variability of temperature series in the figure, several periodic trends are detected. The northwestern and southwestern stations Edirne, Çanakkale, Bolu, Antalya and Ankara show cooling in the period of 1971–1993, where Antalya has the largest cooling trend. Siirt is located on East Anatolia and this cooling trend cannot be clearly seen in its curve. The 1992–1993 years were just after the Mount Pinatubo eruption in the Philippines, when significant amount of particles were forced into the stratosphere, acting as anti-greenhouse agents. Owing to this fact, a majority of Turkish stations show temperatures lower than the normal during this period.

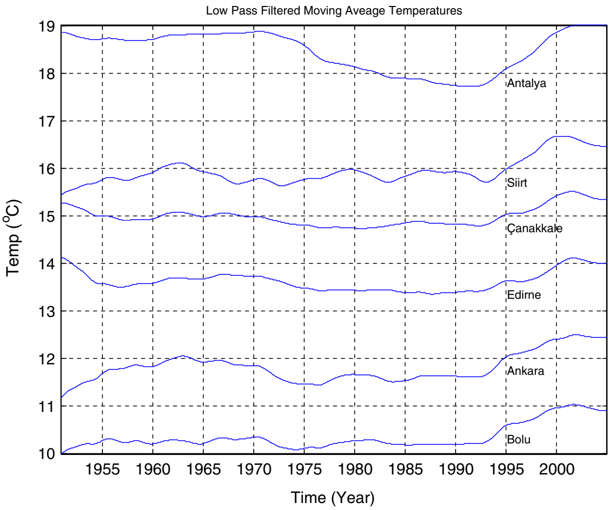


Fig. 4 Low pass filtered moving averages of daily mean temperatures for various selected cities in Turkey

The cooling effect of volcano eruption has been expressed in various studies such as Minnis et al. (1993), Soden et al. (2002) and Robock (2000). Minnis et al. (1993) studied the radiative climate forcing by the Mt. Pinatubo eruption and concluded that the volcanic aerosols caused a strong cooling effect immediately after eruption and the amount of cooling increased through September 1991 as shortwave forcing increased relative to the longwave forcing. Soden et al. (2002) used the global cooling and drying of the atmosphere that was observed after the eruption of Mount Pinatubo to test model predictions of the climate feedback from water vapor. Robock (2000) studied winter lower tropospheric temperature anomalies for the 1991–1992 Northern Hemisphere winter following the 1991 Mount Pinatubo eruption. Author showed that there was winter warming over North America, Europe, and Siberia and winter cooling over Alaska, Greenland, Middle East, and China.

One important conclusion that can be deduced is the obvious temperature increase after 1993, valid in all series presented here. This increase in temperature in the last decade together with a maximum in 2001–2002 and a small decrease afterwards is very closely correlated with the findings of global temperature series analysis (IPCC 2001).

The 365-day moving averages (MA) and their low pass filtered signals (LPFMA) can also be obtained for a group of selected stations together. For this purpose, the average of the daily mean temperatures is calculated from the total group of stations. Then, MA and LPFMA methods are applied to the group average as described. These group averages are calculated for S1 and S2 groups in order to see climatic changes in urban and rural areas separately. The resulting graphs are shown in Fig. 5. Furthermore, (1) to eliminate the effects of larger scale climatic changes, (2) reduce the problem to a micro-scale level and (3) determine the effects of urbanization, the difference temperature series of S2 and S1 averages are obtained and illustrated as Fig. 5b.

In Fig. 5a both series show a cool period starting in the early 1960s and ending in 1993, somehow longer than the cool period seen in the individual series of the previous figure. Since this figure carries the signal of many stations together, it is

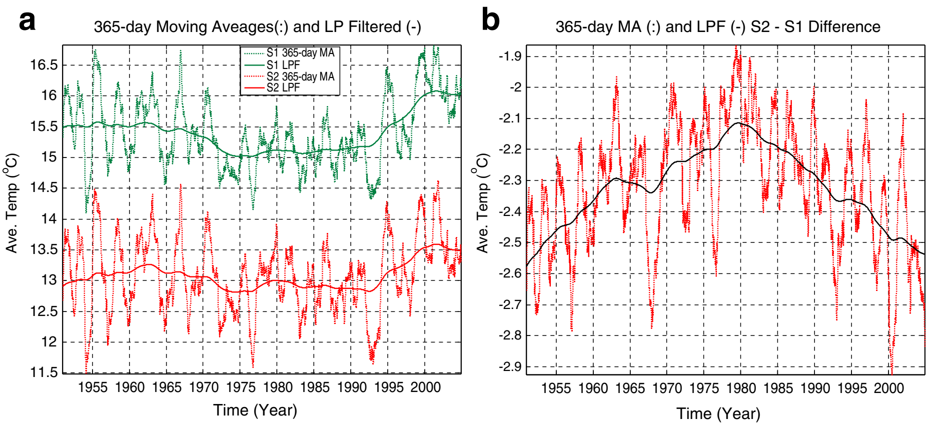


Fig. 5 **a** Moving averages and low pass filtered signals of S1 and S2 mean temperature series, **b** same of (**a**) except for the difference temperature series of S2 and S1 series

much more reliable and intuitive than the signal of individual series. Similar to the individual series, a last decade significant warming trend is observed in both of the series, leading to maximum temperatures in this half century analysis period.

Since Fig. 5b is eliminating the effects of global climate change, it is possible to say that the urbanization forced temperature increase in urban stations is closing the temperature gap till 1980. However, a sudden decrease in the mean temperature difference curve takes place after that critical date. Possibly the main reasons of this can be (1) the stabilization of the urban induced temperature change in urban areas after a certain growth period and (2) the rural and suburban stations also started to be effected by urban problems such as concrete structures and air pollution.

Figure 6a illustrates that the variability of urban precipitation series is generally larger than the rural one, suggesting that urban stations experience the droughts

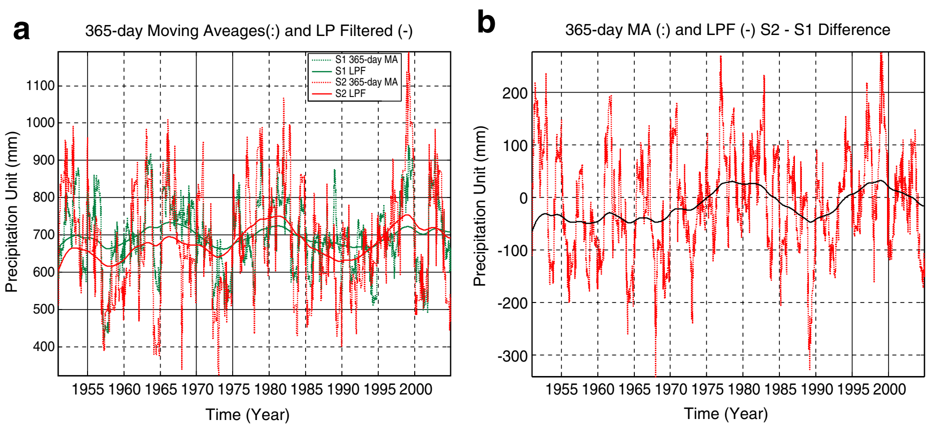


Fig. 6 **a** Moving averages and low pass filtered signals of S1 and S2 precipitation series, **b** same of (**a**) except for the difference precipitation series of S2 and S1 series

stronger and floods more frequent and severe. Though not significant, an increase in the urban precipitation compared to the rural one can be seen in Fig. 6b. This result can be due to increased convective and orographic activity over urban areas.

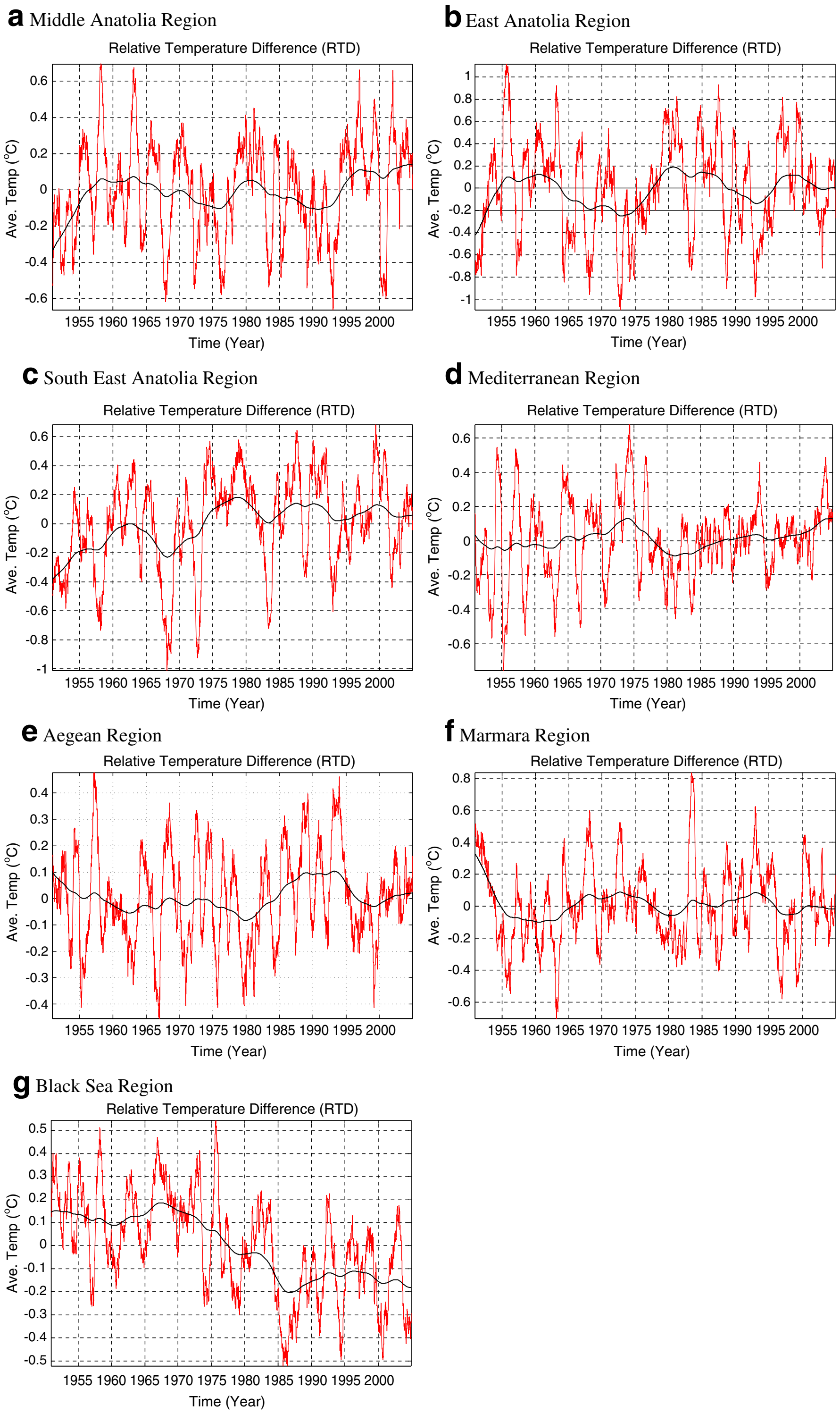
Relative difference (RD) and low pass filtered relative difference (LPFRD) signals are obtained for 1950–2004 period regional average temperature series and are drawn for seven geographic regions of Turkey; Middle Anatolia, East Anatolia, South East Anatolia, Mediterranean, Aegean, Marmara and Black Sea regions, and illustrated in Fig. 7. Middle Anatolia, East Anatolia and South East Anatolia regions are showing generally similar characteristics in mean temperature with high variability in it. These regions are located in inner parts of Anatolia with continental type of climate and this explains the high variability in temperature. It is interesting to note that these regions experience a warming in the 1950s, a cooling period after, continuing until 1976 for the Middle Anatolia Region. After warming periods, Middle and East Anatolia regions again show a cooling period during 1980–1993. East and South East Anatolia regions show cooling in 2000s while Middle Anatolia is almost in a warming period since 1993.

Mediterranean, Aegean, Marmara and Black Sea regions are located in close proximity to sea, thus have a lower variability in mean temperatures. Mediterranean region shows a slight general increase in temperature with an exception of decrease in 1974–1981. Aegean and Marmara regions were under a cooling trend in the first half of 1950s. Afterwards, the variability is very slight, in the $\pm$ 0.1°C range. However, Black Sea Region has a distinct temperature structure. In the 1950s and 60s the temperature was above normal, but after 1968 a decrease of 0.4°C in RD temperature anomaly in 20 years of time scale took place. The last two decades were characterized with 0.1 and 0.2°C below normal RD temperatures.

Relative difference (RD) and low pass filtered relative difference (LPFRD) signals for regional precipitation in the period of 1950–2004 are illustrated for seven geographic regions of Turkey in Fig. 8. Similar to the temperature figures, Middle Anatolia, East Anatolia and South East Anatolia regions are again showing generally similar trends in the precipitation variability. With the onset of 1950s, the wet climate is giving rise to a drier climate for these 3 regions. In Middle Anatolia Region negative precipitation anomaly is dominant in the period of 1952–1973. By focusing on low pass filter curve, it can be said that South East Anatolia Region experienced a very long lower than normal precipitation in the 1958–1986 period, except for several years in the late 1960s. On the other hand East Anatolia Region RD precipitation shows small variation with no general significant trend till 1983. The 1980s are characterized with precipitation increases in those three regions. The maximum positive LPFRD anomaly corresponds to 1987 for Middle Anatolia and the East Anatolia Regions. Unfortunately, those three regions were under negative precipitation anomalies in recent years with the record low RD values.

Recent climatic studies on Eastern Mediterranean (EM) countries generally showed a decreasing trend of rainfall in most of the EM countries (Alpert et al. 2004; Krichak et al. 2000). Despite this fact, it is quite interesting to see that the precipitation of the Mediterranean Region of Turkey is steadily increasing in amount. This result somewhat is in positive correlation with the temperature

Fig. 7 Regional relative temperature differences and their low pass filtered signals ▶


a Middle Anatolia Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
b East Anatolia Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
c South East Anatolia Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
d Mediterranean Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
e Aegean Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
f Marmara Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
g Black Sea Region
Relative Temperature Difference (RTD)
Ave. Temp (°C)
Time (Year)
1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

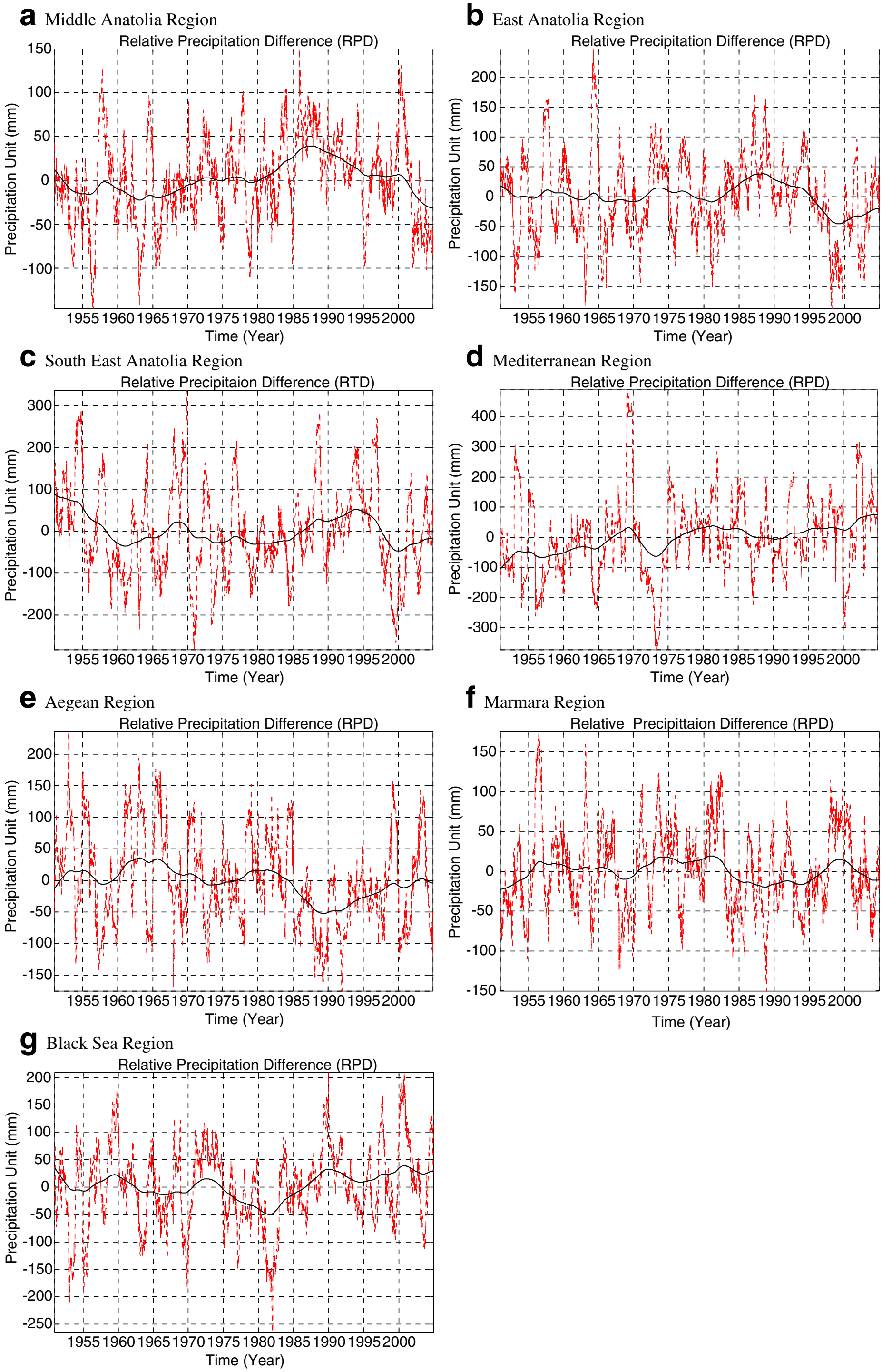


Fig. 8 Regional relative precipitation differences and their low pass filtered signals

series, suggesting that increasing temperatures can also increase precipitation of the Mediterranean Region of Turkey. Contrary, this result is totally different from the results of ICTP-RegCM3 run according to IPCC A2 scenario for 2071–2100 period showing winter and annual precipitation reductions up to 40% for the Turkish Mediterranean area (Alpert et al. 2006; Onol et al. 2006). Both Aegean and Marmara Regions experienced frequent droughts in the late 1980s and 1990s, of whom Aegean was under a worse condition with LPFRD reaching −50 mm anomaly. Black Sea Region is again unique in its precipitation behavior. It experienced the worst drought in 1983 with the LPFRD curve touching −50 mm anomaly. But afterwards, a general increase in the precipitation values, maintained a positive low pass filter anomaly, especially after 1987. This startling result is also the main culprit of frequent recent floods in the area.

3.2 Spatial analysis of Mann–Kendall statistics

The yearly averages calculated for all temperature series show significant warming in southern and southeastern parts and significant cooling in northeastern parts of Turkey. Figure 9 illustrates the spatial distribution of Mann–Kendall statistics as circles. As can be seen from Fig. 9a, there is a significant warming trend in the majority of the Mediterranean Region stations, some eastern Anatolia stations and in Lüleburgaz and in some Istanbul stations in the northwest. Looking at the big picture, one can conclude that almost all parts of Turkey are under a warming trend - mostly not significant - except for the northern parts. On the other hand, there is certainly a much more widespread significant warming trend in the minimum

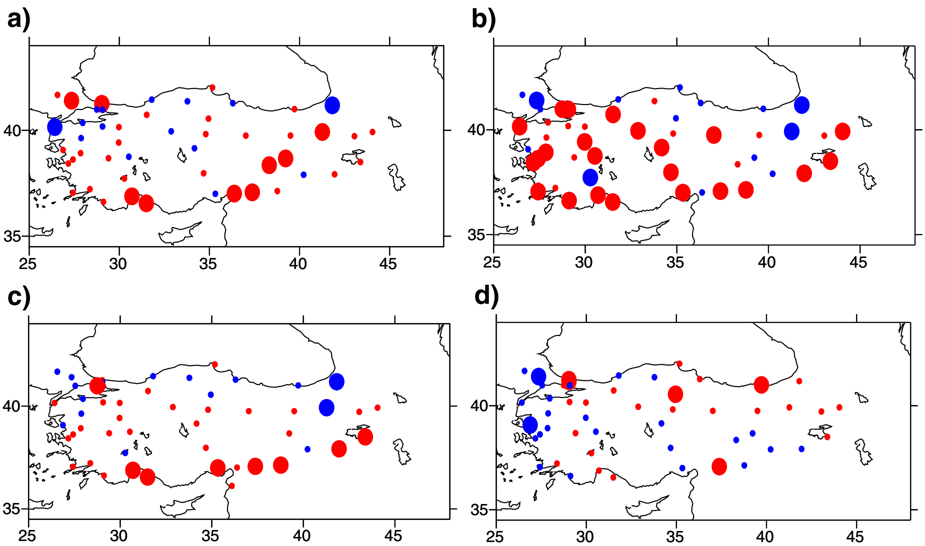


Fig. 9 Spatial distribution of annual **a** maximum, **b** minimum, **c** average temperatures, and **d** precipitation series Mann–Kendall statistics in Turkey (*large filled circles* represent 95% significant warming, *small filled circles* represent warming but not significant, *large empty circles* represent 95% significant cooling and *small empty circles* represents cooling that is not significant)

temperatures (Fig. 9b). Almost all southern parts, western parts and continental regions of the country experienced a warming in minimum temperatures during the last half century. The increase in minimum temperatures can be easily attributed to urbanization and urban heat island effect. The increase in population, thus the increase in residential and industrial areas causes the heat to be absorbed by the buildings and air pollutants, and during the nighttime, when the minimum temperatures are observed, produces an artificial heating source that is called heat islands, increasing the minimum temperatures as well as leading to air pollution episodes.

Figure 9c presents the trends in mean temperatures. Again the increase can be seen in most of the regions of Turkey, with the exception of northern regions. The southeastern regions experience significant warming. The significant increases in the temperatures of the southern parts of the country is believed to be a result of desertification (Tayanç et al. 1997) and the increasing frequency of the Africa and Middle East originated heat waves for the last half century. Another interesting result that can be seen in the figures is that the stations in certain regions of the country show a cooling trend in average temperatures, but show a warming trend in maximum temperatures (e.g. Artvin, Tekirdağ, Edirne, Antalya). This is a result coming from the calculation of average daily temperatures. The formulation includes 0700, 1400 and 2100 LST observations, but 2100 LST observation is included twice in the calculation. Thus, the daily average temperatures are more likely affected by a cooling trend observed in minimum temperatures.

Figure 9d represents the spatial distribution of precipitation throughout the study period. As can be seen from the figure, especially the trend in the southeastern, western and northern parts of the country agrees with the temperature changes discussed above. Across the country, significant changes in precipitation series generally cannot be observed, but on the northern parts, there is a significant increase in the amount of precipitation received yearly. In the Aegean part of the country, though not significant, there is an opposite decreasing trend which is well correlated with the increasing temperatures in that region. Similarly, in the southeastern regions, generally there is a decreasing trend in the amounts of yearly rainfall agreeing well with the idea of desertification.

The decreasing precipitation rates in the Aegean part of Turkey can be related to the positive phase of the North Atlantic Oscillation (NAO) in the recent years. The traditional definition of the NAO is the difference in sea level pressure between a station in Iceland (generally Stykkisholmur, and one in Azores (generally Ponta Delgada). The positive NAO mode has a well developed Icelandic Low and Azores High, associated with stronger westerlies over the eastern Atlantic and Northwest Europe with weaker westerlies over the Mediterranean Basin, while the negative mode has weakened Icelandic Low and Azores High, resulting in a reduction in westerlies over the Northwest Europe but increase in the Mediterranean Basin low pressure systems. Since about 1985, the NAO has tended to remain in a strong positive phase, though with substantial interannual variability. This recent upward trend in the NAO accounts for much of the regional precipitation increase in northern Europe and precipitation decrease in the Mediterranean Basin. Alpert et al. (2004) expressed the high positive correlation between the recent increase in the North Atlantic Oscillation Index and the decrease of precipitation over most of the EM countries. Eshel and Farrell (2000), and Krichak et al. (2000) also established similar relationships between the NAO and precipitation patterns in EM. Karabörk et al. (2005) showed that precipitation, stream flow, maximum temperature and minimum temperature patterns on Turkey have significant negative correlations with the NAO Index.

Owing to the forcing of NAO, Alpert et al. (2004) found that the frequencies of the dry Red Sea Trough (RST) systems nearly doubled since the 1960s from 50 to about 100 days per year, and annual frequency of the Cyprus lows drop slightly in 1983–1998 to 26, compared with about 30 during 1967–1982. This explains the trend of rainfall in most of the EM. Western part of Turkey, especially Aegean Region is the most effected area, where the mountains are perpendicular to the sea shore and precipitation generally is associated with westerlies. Reduction in the number and strength of low pressure systems in the East Mediterranean and the increase in RST systems are expected to decrease the precipitation in the Aegean.

Regarding the seasonal variations in the temperature and precipitation trends, it is found that there is not much significant change in winter in either way, and that maximum temperatures did increase in the southwestern parts and decrease in the northern and continental (central) parts but these changes are not 95 % significant (Fig. 10a). On the other hand, there is significant decrease in maximum winter temperatures in northwestern Turkey (Zonguldak) and in Aegean part (Çanakkale and Dikili). Minimum temperatures increased in central, southeastern and eastern part but decreased in western and northern parts (Fig. 10b). These increases are significant in Alanya and Fethiye stations in southwestern Turkey and in Van station in eastern part of Turkey. Decrease in minimum temperatures are significant in Burdur station in southwestern part, in Dikili station in the Aegean (western) region, Sinop and Samsun stations in northern regions (Black Sea Region) and Erzurum station in eastern part of Turkey. Average temperatures increased in eastern parts

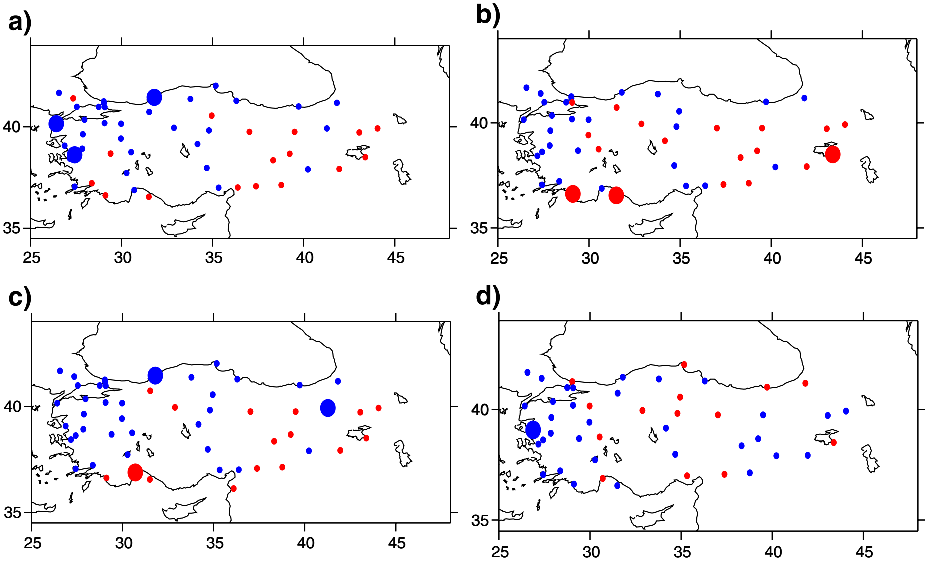


Fig. 10 Same as Fig. 9 for the winter season

and decreased in western parts (Fig. 10c). Those changes are mostly not significant except for an increase in Antalya station and decrease in Zonguldak and Erzurum stations. There is a decrease in the amount of annual precipitation in western and southeastern parts and increase in central and northeastern (East Black Sea Region) regions of Turkey (Fig. 10d). The only significant change is detected in Dikili station as a decrease.

For the spring period, increase in all temperature series and precipitation series is found, especially in minimum temperatures (Fig. 11). Significant increase in maximum temperatures in southern (Antalya and Alanya stations) and northwestern (İstanbul, Edirne and Trakya) regions are detected (Fig. 11a). Minimum temperatures significantly increased in almost all western stations except for Burdur station (Fig. 11b). Increase in southeastern regions is also in 95% significance level. Artvin and Erzurum stations in northeastern regions, together with Diyarbakır and Elazığ stations in southeastern parts experienced significant decrease in minimum temperatures. Increase in average temperatures in southeastern and northwestern and especially in western parts of the country are found, being mostly not significant (Fig. 11c). Stations in Istanbul, Alanya station in southern Turkey, Gaziantep, Siirt and Van stations in southeastern Turkey showed significant increases in their average temperatures. Precipitation amount generally increased in western, southwestern, central and northern parts, all being below 95 % significance level (Fig. 11d). Decrease has mostly been experienced in southeastern regions and some stations in the western parts around İzmir, Bilecik, Kütahya and Afyon stations as well as some stations in north (Zonguldak, Samsun and Kastamonu).

For the summer period, it is clearly seen that significant warming exists in almost all regions, especially in minimum temperatures, including the northern regions (Fig. 12). Maximum temperatures increased in almost all stations, mostly

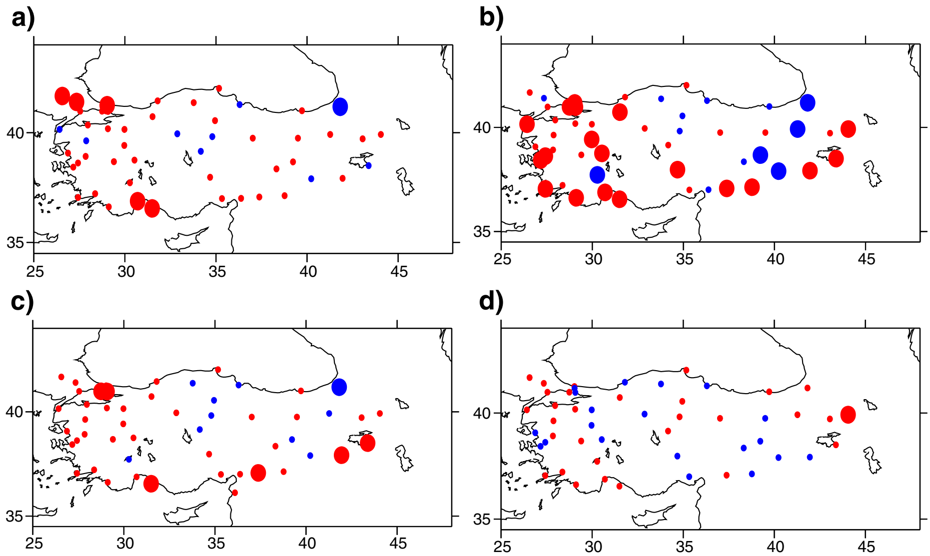


Fig. 11 Same as Fig. 9 for the spring season

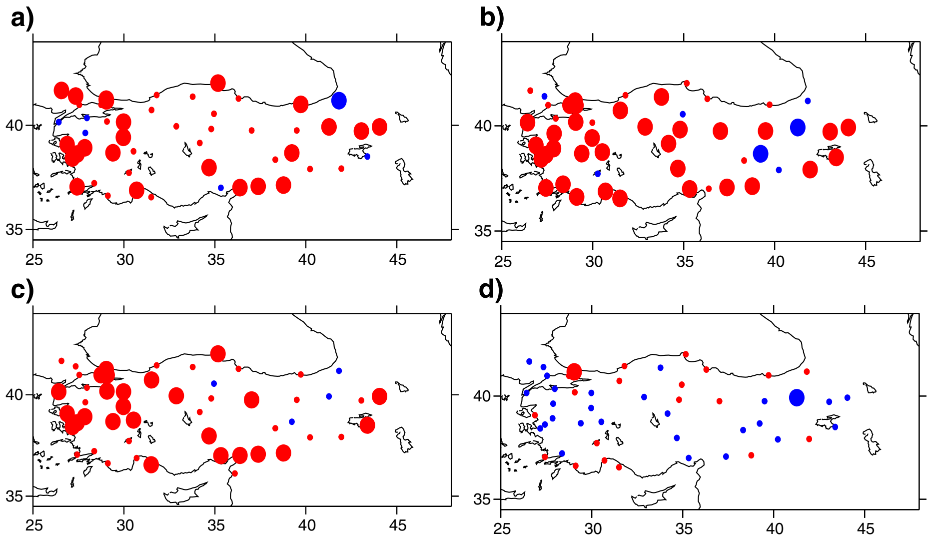


Fig. 12 Same as Fig. 9 for the summer season

significant, and a couple of stations showed opposite trends in the northwestern parts (Fig. 12a). The exceptions are Van in eastern Turkey, Artvin station (significant) in northwestern Turkey, and Bandırma, Balıkesir and Çanakkale stations in Marmara region (northwest). Minimum temperature series almost exhibit the same behavior as maximum temperatures (Fig. 12b). The exceptions are mostly in eastern regions and not significant. On the other hand, Erzurum and Elazığ stations experienced a significant decrease in their minimum temperatures. Average temperatures increased almost significantly throughout the country with the exceptions of Artvin, Erzurum and Elazığ stations in the east (Fig. 12c). Decrease in precipitation in eastern, western and central parts; and increase in northern and southern parts are detected (Fig. 12d). Summer precipitations significantly decreased in Erzurum station and increased in Sarıyer station in the Marmara Region. Decrease in western parts can be attributed to the positive NOA index values as explained before. The increasing temperature values and decreasing precipitation amounts in southeastern regions are a consequence of the desertification taking place in the Middle East Region. This result can be clearly seen in almost all seasonal and annual trends.

Autumn is characterized by increases in temperature and precipitation over most of the country, generally significant in minimum temperatures (Fig. 13). Maximum temperatures increased countrywide though not significant with the exceptions of Antalya and Erzurum stations (Fig. 13a). As can be seen in Fig. 13b, minimum temperatures significantly increased except for the northern coastline, although the trend remains below the significance level. Decrease has also been detected in a few stations, being significant in Erzurum and Elazığ stations and not significant in Artvin, Çorum and Diyarbakır stations. Average temperatures increased in western, central and southern parts and decreased in southwestern parts (Fig. 13c). Significant increase has been detected in Antalya, Alanya, and Adana stations in Mediterranean region, Kırşehir station in central region and Gaziantep in southeastern region.

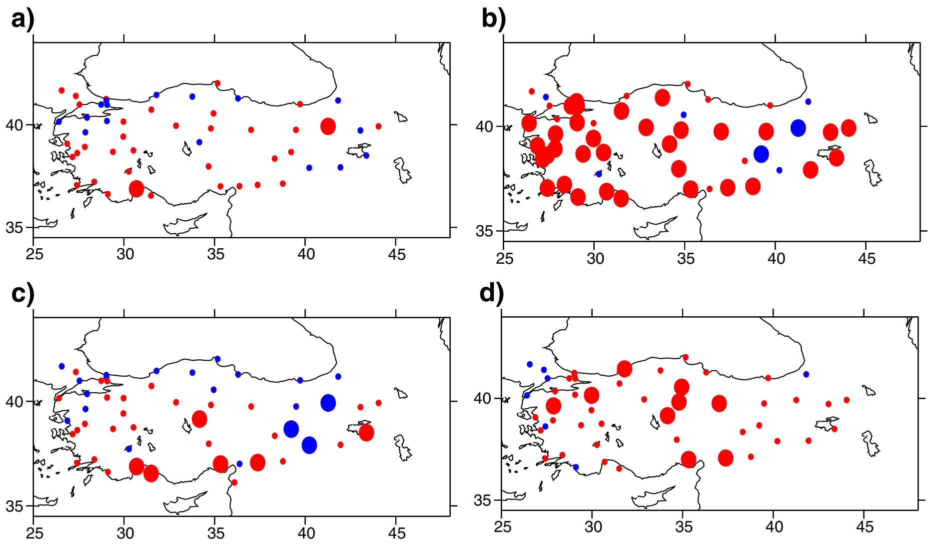


Fig. 13 Same as Fig. 9 for the autumn season

Increase in station based precipitation can be clearly seen in all regions (Fig. 13d). Significant increase has been detected in central parts and northwestern parts. Decrease has also taken place in northwestern parts but is not significant.

Table 2 illustrates the overall linear trends in mean, minimum and maximum temperature series, and urban bias for 55 years. From the data almost no urban bias or a negative trend can be established. This result is important in terms of showing the complex urban micro-climatic properties to be effective on the 'so called' rural stations. When the data in Table 2 is examined together with the Fig. 5, it can be said that the urbanization in cities showed its effect on the temperatures as the other studies suggest. Tayanç et al. (1997) showed that the urban bias for the 1951–1990 period in mean temperatures was 0.24°C/40 years by using the data of the same stations. Fig. 5b shows the difference series to be increasing till the early 1980s. After that date, trend changed into the reverse direction, leading to a decrease in urban bias. Changes in the land-use type of the areas surrounding rural meteorological stations are believed to be the culprit of this result. The urban micro-climate is complex and difficult to understand but some of the main elements playing important role can be listed as (1) constructing tall concrete buildings around the stations prevent ventilation such as Göztepe station in İstanbul, (2) absorbance of heat during daytime and release of it in the form of IR at night lead to the warming up of the

Table 2 Linear trends of mean, minimum and maximum temperatures of Total, S1 and S2 station sets for the period of 55 years

	Change in temperature (°C/55 years)			
	Mean	Minimum	Maximum	Range
Overall average	0.25	0.51	0.31	−0.20
Urban average (S2)	0.25	0.47	0.28	−0.19
Rural average (S1)	0.24	0.68	0.44	−0.24
Urban bias	0.01	−0.21	−0.16	0.05

nearby atmosphere, (3) pollutants emitted from space heating and industrial sources also act as a blanket for IR radiation, etc.. One conclusion that can be underlined here is the necessity of automatic meteorological stations installed in pure rural areas, where there is no inhabitation. Otherwise, the datasets, when gridded and analyzed or used in model initializations, will show urbanization effects as regional or larger scale climatic effects that can be misleading.

4 Conclusions

In this study, annual and seasonal temperature and precipitation data from 52 stations are temporally and spatially analyzed as individually and as groups of S1 and S2. Signal analysis show a cool period extending from early 1960s till 1993, generally with the lowest temperature values on 1992–1993 owing to the eruption of Mount Pinatubo. A last decade significant warming trend is observed in both of the series, S1 and S2, leading to 2000–2002 temperatures to be recorded as maximums in record history.

It is found that the variability of urban precipitation series is generally larger than the rural one, suggesting that urban stations can experience more frequent and severe droughts and floods. Though not significant, an increase in the urban precipitation compared to the rural one is also found. This result can be due to increased convective and orographic activity over the urban areas.

Spatial analysis resulted in significant warming in southern and southeastern parts of the country. Particularly, minimum temperature series show significant warming in almost all regions indicating the effect of urbanization. Seasonal analysis show minimum temperatures in spring, summer and autumn to have significant warming trends. Cooling detected in some stations in the northern parts of the country that is not significant. Significant warming in maximum and mean temperature series, as well as the significant decrease in precipitation, point to desertification in southeastern parts of Turkey.

The decreasing precipitation amounts in the western parts of Turkey, such as Aegean and Trachea regions, can be related to the positive trend of the North Atlantic Oscillation (NAO). On the other hand, northern stations of Turkey generally experiences increases in precipitation of which some are significant. Seasonal analysis show that the winter precipitation, which corresponds to the largest amount of precipitation amount owing to the Mediterranean type of climate, is generally in a decreasing trend throughout the country. Contrary, significant increase in the autumn precipitation in the middle parts of the country is detected.

The increase in population together with the drop of precipitation in the western parts of Turkey and increasing temperatures can produce many risks. One of those risks, probably the most important one, is the increased stress on water resources. Considering the socio-economic diversity of the area, demographic values and climate change, the water resources in Turkey are becoming increasingly more important.

Acknowledgements This study is supported by TUBİTAK-ÇAYDAG with projects 106Y212, 106Y258 and TUBİTAK-KAMAG with project 106G015.

References

Alpert P, Osetinsky I, Zivb B, Shafir H (2004) Semi-objective classification for daily synoptic systems: application to the Eastern Mediterranean climate change. Int J Climatol 24:1001–1011

Alpert P, Krichak SO, Osetinsky I, Dayan M, Haim D, Shafir H (2006) Climatic trends to extremes and regional modeling over the E. Mediterranean. In: Unal YS et al (eds) Int. conf. on climate change and the Middle East. Istanbul Technical University Turkey, November, pp 20–23

Charlson RJ, Wigley TML (1994) Sulfate aerosol and climatic change. Sci Am 270:48–57

Eshel G, Farrell BF (2000) Mechanisms of Eastern Mediterranean rainfall variability. J Atmos Sc 57(19):3219–3232

Ezber Y, Sen OL, Kindap T, Karaca M (2006) Climate effects of urbanization in İstanbul: a statistical and modeling analysis. Int J Climatol 26:1225–1236

IPCC (2001) Intergovernmental panel on climate change. Climate change 2001–the scientific basis: contribution of working group I to the third assessment report of the intergovernmental panel on climate change. In: Houghton JT et al (eds) Cambridge University Press, New York

Jones PD, Mann ME (2004) Climate over past millennia. Rev Geophys 42 RG2002. doi:10.1029/2003RG000143

Kahya E, Karabörk MC (2001) The analysis of el nino and la nina signals in streamflow of Turkey. Int J Climatol 21:1231–1250

Kalaycı S, Kahya E (2006) Assessment of streamflow variability modes in Turkey: 1964–1994. J Hydrol 324:163–177

Karabörk MC, Kahya E, Karaca M (2005) The influences of the Southern and North Atlantic oscillations on climate surface variables in Turkey. Hydrol Process 19:1185–1211

Karaca M, Tayanç M, Toros H (1995) The effects of urbanization on climate of İstanbul and Ankara. Atmos Environ (Urban Atmospheres) 29:3411–3421

Karaca M, Deniz A, Tayanç M (2000) Cyclone track variability over Turkey in association with regional climate. Int J Climatol 20:1225–1236

Karl TR et al (1993) Asymmetric trends of daily maximum and minimum temperature. Bull Amer Meteor Soc 74:1007–1023

Kiehl JT, Schneider TL, Rasch PJ, Barth MC, Wong J (2000) Radiative forcing due to sulfate aerosols from simulations with the national center for atmospheric research community climate model, Version 3. J Geophys Res 105:1441–1457

Krichak SO, Tsidulko M, Alpert P (2000) Monthly synoptic patterns associated with wet/dry conditions in the Eastern Mediterranean. Theor Appl Climatol 65:215–229

Minnis P, Harrison EF, Stowe LL, Gibson GG, Denn FM, Doelling DR, Smith WL Jr (1993) Radiative climate forcing by the Mount Pinatubo eruption. Science 259:1411–1415

Mitra SK (2001) Digital signal processing, 2nd edn. McGraw-Hill

Nasrallah HA, Balling RC (1993) Spatial and temporal analysis of Middle Eastern temperature changes. Clim Change 25:153–161

Onol B, Semazzi FHM, Unal YS, Dalfes HN (2006) Regional climatic impacts of global warming over the eastern Mediterranean. In: Unal YS et al (eds) Int. conf. on climate change and the Middle East. Istanbul Technical University Turkey, November, pp 20–23

Robock A (2000) Volcanic eruptions and climate. Rev Geophys 38:191–219

Soden BJ, Wetherald RT, Stenchikov GL, Robock A (2002) Global cooling after the eruption of Mount Pinatubo: a test of climate feedback by water vapor. Science 296:727–730

Tayanç M, Toros H (1997) Urbanization effects on regional climate change in the case of four large cities of Turkey. Clim Change 35:501–524

Tayanç M, Karaca M, Yenigün O (1997) Annual and seasonal air temperature trend patterns of climate change and urbanization effects in relation with air pollutants in Turkey. J Geophys Res No. D2 102:1909–1919

Tayanç M, Dalfes HN, Karaca M, Yenigün O (1998a) A comparative assessment of different methodologies for detecting inhomogeneities in Turkish temperature dataset. Int J Climatol 18:561–578

Tayanç M, Karaca M, Dalfes HN (1998b) March 1987 cyclone (blizzard) over the eastern Mediterranean and Balkan region associated with blocking. Mon Wea Rev 126:3036–3047

Wigley TML (2005) The climate change commitment. Science 1766–1769, 18 March

WMO (1992) Monitoring, assessment and combat of drought and desertification. WMO/TD-No.505 Geneva