Vol. 70: 77–93, 2016
doi: 10.3354/cr01410

CLIMATE RESEARCH
Clim Res

Published September 26

Has the climate been changing in Turkey? Regional climate change signals based on a comparative statistical analysis of two consecutive time periods, 1950–1980 and 1981–2010

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ABSTRACT: In this study, the climate zones of Turkey were re-examined using different objective statistical tests based on the differences in the behaviour of meteorological variables, and a comparative analysis of 2 consecutive periods was performed statistically. The data consisted of total precipitation, and minimum, maximum and mean air temperature series recorded from 1950–2010 at 244 climatological/meteorological stations operated by the Turkish Meteorological Service. *K*-means and hierarchical clustering methods were applied separately to each variable to obtain surface air temperature and precipitation patterns in Turkey for the periods of 1950–1980 and 1981–2010. Paired-samples Student's *t*-test (paired *t*-test) and Pitman-Morgan (P-M) *t*-test were used to detect possible changes in the mean and variance of the series in the transition from one period to the other. The results of the analysis reveal that the climate characteristics of Turkey are generally similar for the temperature series under study. However, there are some changes in the existing geographical patterns of the climate regions. Statistical tests show that all 3 air temperature series increased after 1980. The major changes appeared in the precipitation regions of Turkey: there were significant changes in the continental central, central-west and central-east Anatolia regions, and in the continental north and eastern Anatolia region. It was also apparent that precipitation amounts increased in the northern and eastern regions of Turkey after 1980, but amounts decreased in the west, central and southern regions, most of which are generally characterized as having a dry summer subtropical Mediterranean climate.

KEY WORDS: Turkey · Mediterranean climate · Abrupt climate change · *k*-means · Hierarchical clustering · Statistical comparison tests

1. INTRODUCTION

Climate change is one of the most significant and far-reaching challenges that human societies face in the 21st century, as its effects are felt in physical geographical, ecological and socio-economic systems. According to the latest scientific assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013), the Earth's globally averaged surface temperature has increased by 0.85°C (0.65–1.06°C) over the past 100 yr with evident regional variations. The rate of warming over the period from 1951–2012 was about 0.72°C (0.49–0.89°C) (IPCC 2013). Other climatic elements, including precipitation amounts, types and variability, snow and ice cover patterns and mean sea level have also been changing.

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Current climate research focuses on 2 major concerns. The first involves evaluating the changes in the climate and its components (Chung et al. 2004, Norrant & Douguedroit 2006, Freiwan & Kadioglu 2008, Iyigun et al. 2013). The second concern involves describing climate regions and/or assessing rainfall regime regions (e.g. Türkeş 1996, 1998, Malmgren & Winter 1999, Mimmack et al. 2001, Unal et al. 2003, Alijani et al. 2008, Sönmez & Kömüşcü 2011. Türkeş & Tatlı 2011, Sahin & Cigizoglu 2012). In the following literature review, we have chosen peer-reviewed studies related to both concerns of climate. Over the past few decades, studies related to climate change detection and abrupt climate changes have become more important. For instance, Sönmez & Kömüşcü (2011) redefined main precipitation clusters in Turkey using *k*-means methodology, and detected spatial shifts in the redefined rainfall clusters in subsequent periods over the last 30 yr with respect to North Atlantic Oscillation (NAO) patterns. Among other things, they found that temporally drier and wetter clusters were occurring from one decade to another, with underlying shifting causes in relation to the NAO patterns. Guolin et al. (2010) reviewed new methods of climate change detection and partitioned the methods into different categories, namely: abrupt climate change detection, signal separation and extraction from observed data, and definitions and detection of extreme events. According to the Kerner Oceanity Index applied to Turkish climate data, Deniz et al. (2011) indicated that marine climate characteristics are more dominant in the Black Sea region than in the Aegean and Mediterranean region. Across 25% of Turkey, a continental effect was found, with maximum continentality found in the eastern Anatolia region. They also showed that semi-dry areas increased in the 1991–2006 period compared to 1960–1990. Toros (2012) detected that temperatures began to increase at the beginning of the 1980s. Unal et al. (2013) found that the number of hot days, heat waves and heat wave durations increased between 1965 and 2006 in the western part of Turkey, and the rate of change also increased in the last decade, along with an increase in the frequency of extreme events since 1998. Some studies dealing with abrupt changes include Qiang & Congbin (1992), Hasselmann (1998), Loehle (2004), Pitman & Stouffer (2006), Swanson (2006), Zhang et al. (2006), Fangfang et al. (2007), Ribes et al. (2009), Sun et al. (2010), Ribes et al. (2010), and Huang et al. (2013). Studies focusing on signal separation and extraction from observed data include Hegerl et al. (2006), Sebastiao et al. (2009), Lackner et al. (2011), Long et al. (2014), and Stephenson et al. (2014).

The Mediterranean Basin and Turkey are located in the regions that will be most influenced by the adverse impacts of observed and projected climate change, including variability in hydrology and water resources, natural ecosystems, agriculture and food security associated with extreme weather and climate events and disasters (e.g. Türkeş et al. 2002, 2009a,b, 2011, Trigo et al. 2006, Türkeş & Tatlı 2009, Erlat & Türkeş 2012, 2013, Lelieveld et al. 2012, Ozturk et al. 2012, Türkeş 2012, 2013, 2014a,b, Altinsoy et al. 2013, Tatlı & Türkeş 2014, Türkeş & Altan 2014). We evaluated projected future (up to 2100) changes and variability in annual and seasonal air temperature and precipitation climatology, including inter-annual variability and drought conditions over the Mediterranean Basin and Turkey (e.g. Ozturk et al. 2012, 2015, Sen et al. 2012, Altinsoy et al. 2013, Onol & Unal 2014, Turp et al. 2014, Sen et al. 2015). For instance, based on projected climate changes over Turkey, using reference (1961–1990) and future (2071–2100) climate simulations produced by the Abdus Salam International Centre for Theoretical Physics reginal climate model version 3 (ICTP-RegCM3), Onol & Unal (2014) found that air temperature increases in the climatic regions of Turkey and summer warming over the western regions will be about 3°C higher than the winter warming. In the future simulation for winter, precipitation amounts decrease significantly over the south-eastern part of Turkey. Sen et al. (2015) also showed that temperatures (especially in summer) are increasing throughout the country, and that snow melts earlier than before. They did not report any significant changes in precipitation.

The first pioneering studies on the climate of Turkey and its spatial and temporal variations were performed by Erinç (1949, 1950, 1969). In these published peer-reviewed papers and his famous, broader-content text book, Erinç determined the climatic types and the variations of moisture and/or arid regions in Turkey based on various climate indices and his own aridity index, namely 'Erinç's Aridity or Rainfall Efficiency Index'. The present climate of Turkey is mainly characterised as a dry summer subtropical Mediterranean climate, which is found in the regions between the subtropical belt and the mid-latitudes, and which generally develops on the western side of continents. However, the Turkish climate also includes a number of sub-climates and rainfall regimes that are mainly due to variations in the synoptic and semi-hemispheric atmospheric circulation and weather systems that originate from the mid-latitude and subtropical geographical zones, along with the diversity and variations in topographic and geomorphologic characteristics within short distances (Türkeş 2010, 2015).

In the present study, we make use of conclusions that arose from previous studies that revealed the existence of 7 major climate and precipitation regime regions and sub-regions in Turkey (e.g. Fahmi et al. 2011, Kartal et al. 2011, Türkeş & Tatli 2011, Sahin & Cigizoglu 2012, Iyigun et al. 2013). A new approach was used in which 2 consecutive periods, each covering 3 decades (1950–1980 and 1981–2010), were compared. Hereafter, for the sake of brevity these periods are also referred to as 'before 1980' and 'after 1980', respectively. In this way, we would expect to see any effect of human-induced climate forcing from the 1980s on the climate of Turkey. This comparison involved the clustering of 4 different climatological variables; namely, mean, maximum and minimum air temperatures (Tmean, Tmax and Tmin, repectively), and total precipitation, obtained from 244 climatological/meteorological stations operated by the Turkish Meteorological Service (TMS). Subsequently, differences in these meteorological variables in common climate regions were statistically tested using the paired-samples Student's *t*-test (paired *t*-test) and Pitman-Morgan (P-M) *t*-test. In order to investigate the boundaries of the regions based on the given dataset, we compared distinct numbers of clusters/regions found by *k*-means and hierarchical clustering. From both objective and subjective analyses, we observed that 7 regions validate the current geographical and climatological knowledge.

The paper is organized as follows. In Section 2, the data and methods used in the study are provided. The new approach used in the comparison of the 2 consecutive time periods and its application are described in Section 3. In Sections 4 and 5, the results of analyses and a discussion are presented, respectively. In the last section, conclusions are stated and future studies are recommended.

2. DATA AND METHODS

2.1. Climate data

This study used climatic data involving monthly Tmean, Tmax and Tmin and total precipitation obtained from the TMS. These data were recorded from 1950–2010 at 277 stations, which are evenly distributed all over the country. However, a significant number of these stations suffer from missing data. To overcome this problem, the Expectation Maximization-Markov Chain Monte Carlo (EM-MCMC) multiple imputation method suggested by Yozgatligil et al. (2013) was used. The main advantage of this method is that it can decrease the amount of imputation uncertainty that arises from missing data by evaluating its sampling variability. Here, the EM algorithm, developed by Little & Rubin (1987), is a method of finding maximum likelihood estimates of the parametric models for incomplete data. The resulting estimates provide a good starting value for beginning the MCMC process, where parameters of the entire joint posterior distribution of the unknown quantities can be estimated by simulation. It consists of 2 steps: imputation (I-step) and posterior (P-step). With the estimated mean vector and covariance matrix, the I-step simulates the missing values for each observation independently. Next, the P-step simulates the posterior population mean vector and covariance matrix from the complete sample estimates. These new estimates are then used in the I-step. In the case of no prior information about the mean and the covariance estimates, a non-informative prior — specifically, the Jeffreys prior (Jeffreys 1946 — is used. This prior distribution is invariant to smooth and monotone transformation of the parameter; hence, under transformation the results will be the same. These 2 steps are iterated long enough to obtain reliable results for a multiply imputed dataset (Schafer 1997, p. 72). After obtaining a stationary distribution, one can simulate an approximately independent draw of the missing values in the series.

In this application, all stations used in the study included monthly data from 1950–2010, because we imputed the series with <50% missing observations using the EM-MCMC method described above, and left the rest of stations (i.e. 33 out of 277) out of the analysis. As a result, the climatic data used in the analysis consists of 244 stations. We provide observation periods as well as the proportion of missing observations from all stations obtained from TMS in the Supplement at www.int-res.com/articles/suppl/c070p077_supp.pdf.

2.2. Methods of clustering

For the detection of climate regions in Turkey, we chose 2 well-known clustering methods (hierarchical and *k*-means methods) based on the results of our recent studies (Fahmi et al. 2011, Iyigun et al. 2013), and because they have been proven to be successful in detecting climate regions.

2.2.1 The hierarchical method

This method is based on a tree-like construction of data in clustering. This tree structure is called the dendrogram, and in this approach, the roots of dendrogram indicate the clusters and each branch represents an individual observation. Consequently, by using a measure of similarity such as Euclidian, Manhattan, or correlation, a distance matrix of the observations is generated. The values close to each other in this matrix are then combined within the same cluster, and a new iteration is formed by constructing a novel distance matrix under these combined values and remaining observations. From this new matrix, the aim again is to merge the closer values. In this way, if the selected new item/observation is closer to the previous cluster, it is included there; if not, it is considered as a separate branch (or leaf) of the root by generating a new class for the other term(s). This process continues until all observations become a member of a cluster. At the end of this process, we observe a single class at the top of the tree, and all other branches are seen as a leaf of this major class. The underlying structure is also known as 'agglomerative hierarchical clustering' since one starts at the leaves and iteratively combines clusters. Similarly, such a tree structure can also be generated by a divisive approach, in which we begin the clustering from the top with a unique cluster and recursively split this major root into sub-clusters until each observation represents a separate class. However, the former strategy is more efficient than the latter (Everitt et al. 2001).

Each cluster uses one of the linkage criteria, which are used to compute the distance matrix within the agglomerative clustering construction. There are 4 main types of linkage measures: single, average, complete and Ward linkages. Among these alternatives, we chose the Ward linkage for our dataset since it is based on the minimization of the error sum of squares (SS) within the cluster, and from our previous experience with this method, we determined that its results can successfully validate the geographical autocorrelation knowledge about the data, and can separate the clusters more precisely (Fahmi et al. 2011, Iyigun et al. 2013).

2.2.2. The *k*-means method

This method is one of the more well-known clustering algorithms, whose computation is based on optimization of the relocation of the mean of each cluster in such a way that the SS of the difference between the cluster mean and observations of that cluster is a minimum (Everitt et al. 2001). In this clustering, the number of clusters (k) needs to be specified in advance. The elbow plot is a common approach in the selection of k. In this scheme, the value that gives the highest difference in the slope of the curve in the graph of k versus the SS is recognized to be the best value of k. However, there is no unique method for evaluating the clusters. Hence, for each given k, the method finds the best optimal clustering. A graphical illustration of 2 clusters, whose centers are denoted by a solid triangle and circle, respectively, obtained from k-means clustering is shown in Fig. 1.

In this algorithm, the partition of clusters and their centers are minimized by a predefined distance measure. The k-means algorithm typically uses the square of the Euclidean or Manhattan distance as the measure, but any other symmetric and non-negative distance measure can also be used. Since any choice of cluster centers is allowed in this method, occasionally it can produce locally optimal clusters. Furthermore, if the data have a hierarchical nature, this algorithm may not capture this property, since it is non-hierarchical (Wit & McClure 2004).

2.3. Statistical methods of comparison

2.3.1. Paired-samples Student's *t*-test (paired *t*-test)

The paired t-test is a well-known statistical technique used to compare the means of 2 populations in cases where the 2 samples are correlated. It is mainly used in 'before/after' studies, or when the sample

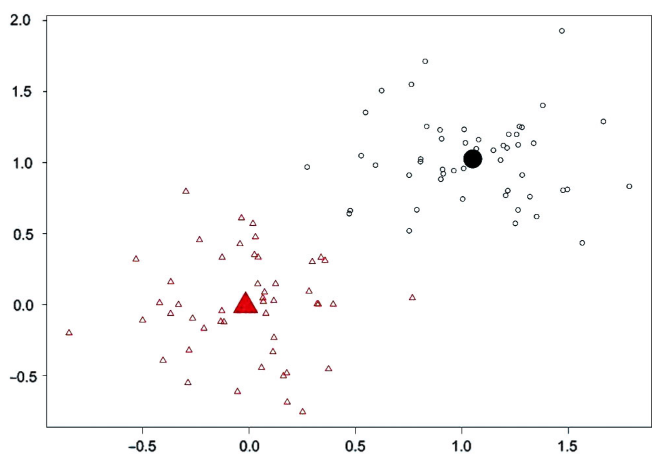

Fig. 1. Two clusters obtained from k-means clustering (k = 2). ○, △) Observations in (○) Cluster 1 and (△) cluster 2; (●, ▲) centres of the 2 clusters

populations are matched pairs. In the present study, the paired t-test was used to detect differences in the means of variables between the 2 time periods (1950–1980 and 1981–2010). The significance of the difference between the 2 periods was checked using the 2-tailed Student's t-test for the equality of means with $(n_1 + n_2 - 2)$ degrees of freedom. Here, n_1 and n_2 were the number of observations in the before and after periods, respectively.

2.3.2. Pitman-Morgan t-test (P-M t-test)

The P-M t-test is used for testing the equality of the correlated variances of the components (here, between the variances of the 2 comparison periods) of a bivariate normal vector. If $\boldsymbol{x}, \boldsymbol{x}' = (X_1, X_2)$ is a bivariate normal vector with variances $\mathrm{Var}(X_1) = \sigma_1^2$ an $\mathrm{Var}(X_2) = \sigma_2^2$, then y is also bivariate normal as:

$$\boldsymbol{y}' = (Y_1, Y_2) = (X_1 + X_2, X_1 + X_2) \quad (1)$$

and

$$\mathrm{Coverance}(Y_1, Y_2) = \sigma_1^2 - \sigma_2^2 \quad (2)$$

Pitman (1939) showed that testing H_0: $\sigma_1^2 = \sigma_2^2$ versus H_0: $\sigma_1^2 \neq \sigma_2^2$ is equivalent to testing independence between Y_1 and Y_2. Hence, testing the equality of variances in a bivariate random sample X_i, $i = 1, 2, \ldots, n$ is based on the following statistic:

$$t = \frac{\mathrm{r}\sqrt{n-2}}{\sqrt{1-r^2}} \quad (3)$$

where r is the Pearson's (sample) correlation coefficient between Y_1 and Y_2. Under the null hypothesis, t has a Student's t-distribution with $(n - 2)$ degrees of freedom. Here, n is the number of observations. Morgan (1939) obtained the same results using the likelihood ratio test.

The main assumptions of these tests are the normality of the distribution of variables and the dependency between the 2 datasets. The assumption of normality was tested using the Shapiro-Wilk normality test (Shapiro & Wilk 1965). After removal of outliers, the normality assumption was satisfied and all tests were applied.

3. THE NEW APPROACH AND ITS APPLICATION

In previous studies, the typical approach has been to investigate changes in the long-term mean of time-series (i.e. long-term trend) to determine if there is a statistically significant long-term change in the characteristics of the meteorological variables being studied. The new approach indicates if there are any changes both in means and variance of the series by comparing these parameters for 2 consecutive periods. In addition, this approach also provides regional patterns in which these variables are homogeneous. In other words, it gives us the patterns of the climate regions that emerge in each of the consecutive time periods with respect to the variables of interest. Thus, we can identify the series in which characteristics change from one period to another. However, we must note here that in order to use the proposed procedure, at least 30 yr of data within the 2 periods should be available, since this length of time is required in order to effectively determine if the change in climate exists.

To detect any possible climate change in Turkey, we first analysed the data using descriptive and graphical statistical methods (Tables 1 & 2, Figs. 2 & 3). The interpretation of these results is presented in Section 4.1. Next, hierarchical and k-means clustering methods were applied to total precipitation, and average Tmin, Tmax and Tmean, and this was done separately for the 2 consecutive time periods. Previous studies by Sahin & Cigizoglu (2012), Iyigun et al. (2013), Fahmi et al. (2011) and Kartal et al. (2011) have shown that the Ward hierarchical clustering method is the most appropriate choice among the other distance calculation methods for the Turkish climate data. Because of this, we only considered the Ward method as the hierarchical clustering method.

The most challenging part of clustering is the determination of the number of clusters, k. To decide k, we considered the results of k-means and hierarchical clustering methods simultaneously. Whenever we obtained the same number of clusters with a similar pattern, we used that

Table 1. Descriptive statistics related to the long-term series of air temperatures and total precipitation variables calculated for the whole time period (1950–2010), for all of Turkey

	Tmax (°C)	Tmin (°C)	Tmean (°C)	Tot. precip. (mm)
Long-term average	25.54	1.46	13.01	52.68
SD	8.94	9.73	8.68	57.20
Minimum	−16.40	−45.60	−21.30	0.00
Maximum	50.00	27.00	37.30	907.20
Kurtosis	2.43	3.22	2.48	13.69
Skewness	−0.33	−0.48	−0.21	2.49

Table 2. Descriptive statistics related to the air temperatures and total precipitation variables calculated for the time periods 1950–1980 and 1981–2010 for all of Turkey

	Tmax (°C)		Tmin (°C)		Tmean (°C)		Tot. precip. (mm)	
	1950–1980	1981–2010	1950–1980	1981–2010	1950–1980	1981–2010	1950–1980	1981–2010
Long-term average	25.38	25.71	1.29	1.63	12.92	13.11	53.09	52.26
SD	8.86	9.01	9.61	9.85	8.43	8.92	56.67	57.75
Minimum	−16.40	−3.00	−45.60	−42.80	−21.30	−17.60	0.00	0.00
Maximum	50.00	49.80	25.20	27.00	35.70	37.30	797.80	907.20
Kurtosis	2.47	2.40	3.25	3.189	2.55	2.41	12.65	14.68
Skewness	−0.35	−0.32	−0.52	−0.44	−0.24	−0.20	2.41	2.56

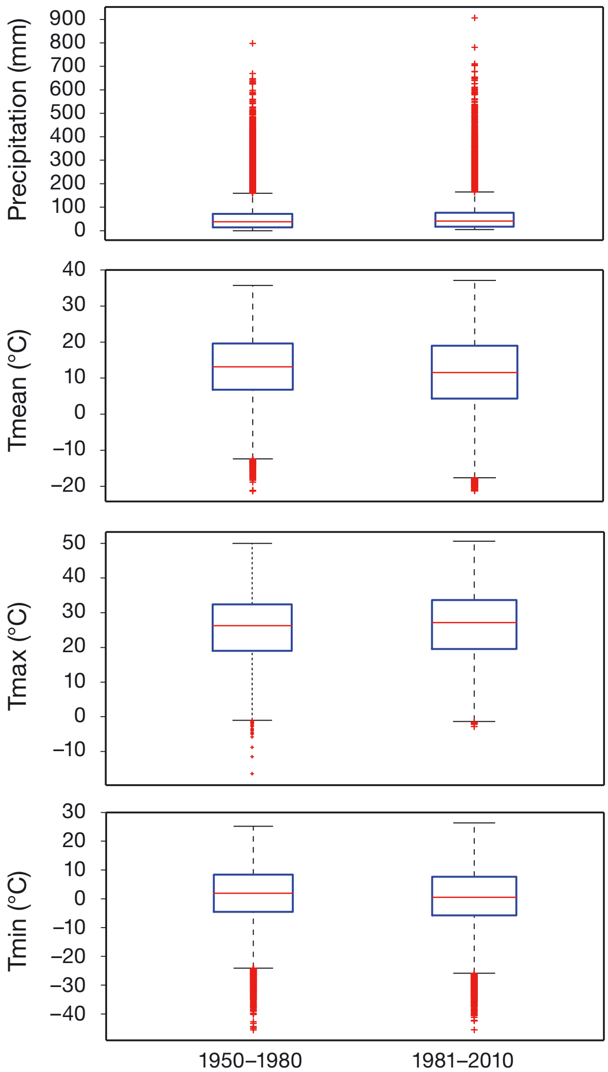

Fig. 2. Box-plots of precipitation, and mean, maximum and minimum air temperature series for the periods of 1950–1980 and 1981–2010

number. To determine the number of clusters in the *k*-means method, the elbow approach was used. A dendrogram was utilized for the hierarchical clustering method. In the *k*-means method, for a given number of clusters, clustering was started by providing the number of clusters, but in the hierarchical clustering method, clusters were obtained sequentially by separating the existing clusters. Hence, hierarchical clustering was better for determining sub-regions. In the present study, we decided to use 7 clusters for all 4 variables based on the results of both *k*-means and hierarchical methods. In the case of more than 7 clusters, sub-regions were formed from main regions using the hierarchical clustering method. In previous studies on the precipitation regions of Turkey, the final decisions on the number of regions in each case was 7 (e.g. Türkeş 1996, 1998, Fahmi et al. 2011, Kartal et al. 2011, Türkeş & Tatlı 2011, Sahin & Cigizoglu 2012), which is consistent with our results.

The clusters obtained from the *k*-means (Fig. 4) and hierarchical clustering methods are very similar (see Fig. 5). Therefore, we decided to use only the hierarchical clustering method for the statistical analyses and assessment of the results. We analysed the clusters of the 4 variables separately and compared the results obtained from the 1950–1980 and 1981–2010 time periods. The pattern observed was that in the 2 consecutive time periods, the main regions were generally the same; although some regions became narrower, while the others became wider. In Fig. 5, the main clusters are represented by the numbers from 1 to 7. When a station in one time period was placed into a different cluster in the other time period, it was labelled with a number >7, and named as a sub-region. The names of the regions were taken from Türkeş & Tatlı (2011) and Iyigun et al. (2013). In some cases, even though the clusters of the 2 periods could be the same, the mean values of the variables could be higher or lower, or there could be changes in variability. Therefore, the paired *t*-test was applied in order to detect whether there were mean differences in the variables between the 2 time periods, and a P-M *t*-test was used to detect differences in the variances of the variables recorded at the stations found in common in the comparative analysis.

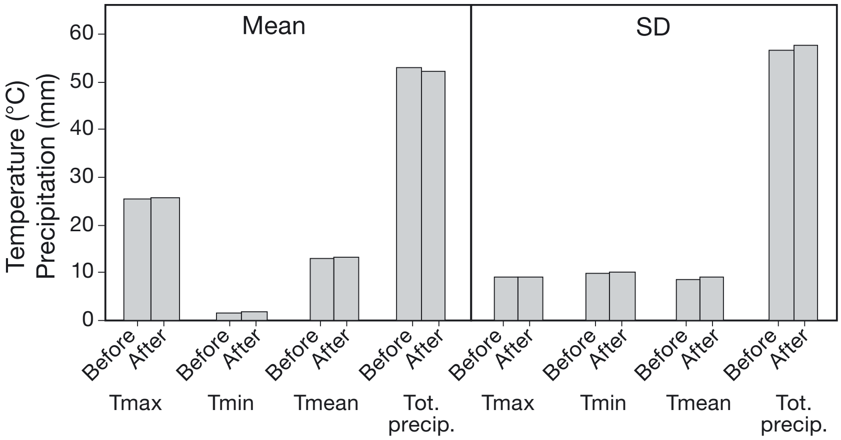

Fig. 3. Long-term averages and standard deviations of air temperatures and total precipitation variables calculated before and after 1980 for all of Turkey

4. RESULTS

4.1. Descriptive analysis of data

Descriptive statistics of monthly Tmean, Tmax and Tmin, and total precipitation for the whole time period (1950–2010), and for the periods before and after 1980 (1950–1980 and 1981–2010) for all of Turkey are given in Tables 1 & 2. In the same section, comparative box-plots of variables for the 2 consecutive time periods are shown (Fig. 2), and bar charts showing averages and SD of all variables for Turkey before and after 1980 are presented (Fig. 3). Here, the results are briefly summarized:

- There were slight increases in the averages in the temperature series, whereas there was a small decrease in the average of total precipitation after 1980.
- In all series, an increase in SDs can be observed after 1980.
- Although there was little or no change in the mean of the variables, a change in variability was noticeable. Note that a greater variability in climatological elements is one of the main indicators of climate change.
- During 1950–1980, more events were out of quartiles (i.e. outliers) in the temperature series. This means that the extreme events seen during 1950–1980 were more frequent than those during 1981–2010.
- In the temperature series, both average Tmin and Tmax values increased, and there was an especially large increase (from −16.40 to −3.00°C) in the minimum of Tmax in the second period.
- After 1980, the maximum total precipitation amounts increased significantly (from 798 to 907 mm), signalling the onset of a period with a greater risk of more extreme precipitation and floods.

4.2. Comparative analysis of clusters

Below, we interpret the results of the comparative analysis of the clusters obtained from the 2 time periods (before and after 1980) for 4 variables of interest, separately.

4.2.1. Tmean patterns

An approximation of the 7 major geographical regions of Turkey, namely the Black Sea, Aegean (i.e. coastal west Anatolia), Marmara, Mediterranean and the continental central, and eastern and southeastern Anatolia regions can be seen in the 2 time periods (Fig. 5). The clusters/regions that emerged are outlined in Table 3. Comparison of the results indicates the following:

- One cluster (Cluster 6) was observed before 1980, but not afterwards.
- One region in the whole time period (1950–2010) contained 13 uncommon stations collected under Cluster 9.
- Before 1980, Cluster 5 was associated with a Mediterranean climate and located within the coastal Mediterranean region, whereas after 1980 some northern parts of it, in addition to the pattern of the Cluster 5 stations, moved over to Cluster 8.
- Cluster 1 was almost the same in both time periods.
- Whilst the southern part of the Cluster 2 pattern did not change, after 1980, Cluster 7 (excluding the Istanbul, Kocaeli and Yalova districts which remained with Cluster 1), separated from Cluster 2. While the mean temperatures of both the Marmara and Aegean regions increased, that increase was smaller in the Marmara region (see Table 4).
- After 1980, Cluster 3 became the widest region, evidently dominating the climate of Turkey. The main characteristics of this region are a dry subhumid and semi-arid mesothermal and microthermal climate with vegetation formations including dry forests, and large steppe and grassland biotopes over the high plains, plateaus and highlands (Türkeş 2010, 2015).

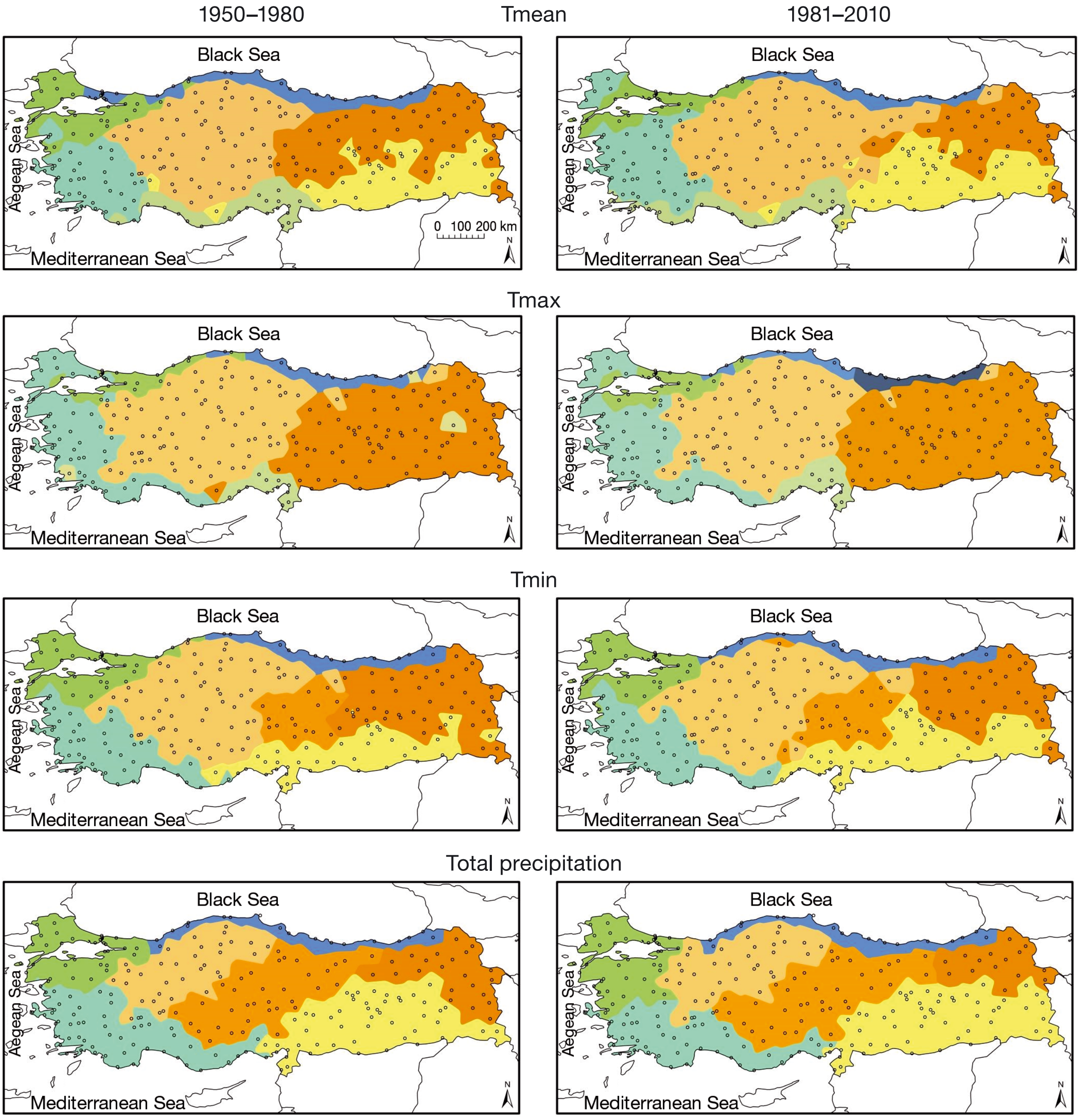

Fig. 4. Regions obtained from a *k*-means clustering method, for the periods 1950–1980 and 1981–2010. Colours: regional clusters; circles: stations

- Most parts of the continental south-eastern Anatolia region (Cluster 5) became part of Cluster 8 after 1980.
- In the period before 1980, the appearance of a regional pattern in Cluster 6 was detected, but this ceased to exist after 1980 between the continental eastern and continental Mediterranean regions. Although this region was the coolest part of Turkey, with a regionally averaged mean air temperature of 8.84°C in the first period, after 1980 temperatures increased and the region showed the same characteristics as Cluster 4.
- A narrow transition zone (Cluster 10) was included as a part of Cluster 4 before 1980, but part of Cluster 3 afterwards.

To investigate the differences in the mean and variance of Tmean statistically, the paired *t*-test and P-M *t*-test, respectively, were applied, and the results are given in Table 4, Figs. 6 & 7). Below, we highlight some statistically significant inferences:

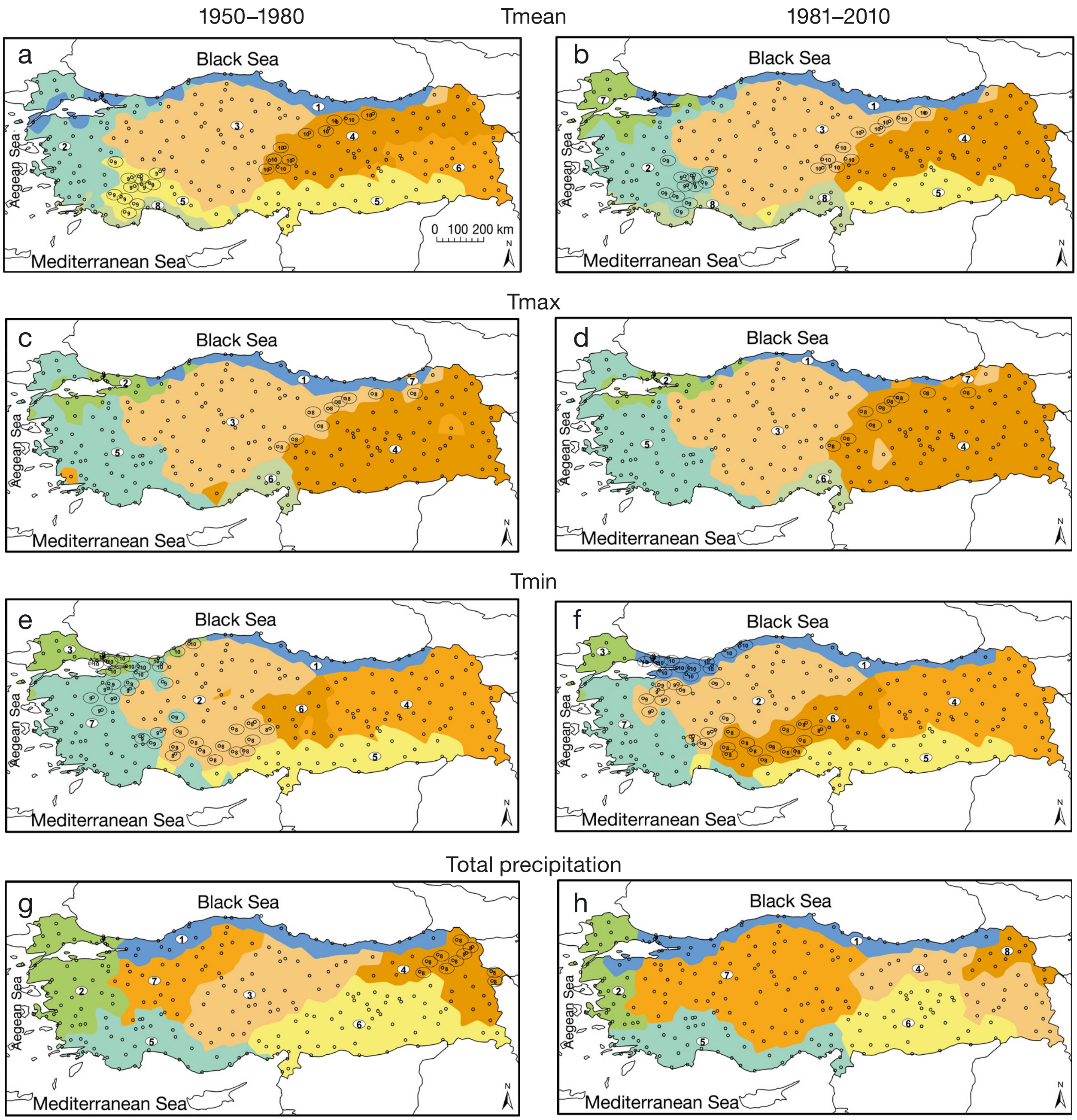

Fig. 5. Regions obtained from a hierarchical clustering method for (a,b) mean air temperature, (c,d) maximum air temperature, (e,f) minimum air temperature, and (g,h) precipitation regime (see Tables 3, 5, 7 & 9 for mean, max. and min. temperature, and precipitation regime cluster numbers, respectively) for 1950–1980 and 1981–2010. Clear ovals with numbers: clusters changing by time; white ovals with large numbers: clusters not changing by time

- Although Cluster 1 appeared to stay the same, the Tmean and year-to-year variability increased from one period to the other.
- The Tmean increased in all regions after 1980.
- In Cluster 2, there was a significant increase in the variance of the Tmean.
- In Cluster 9, while the south-western sub-region (Cluster 5) pattern was seen before 1980, afterwards, its characteristic changed to the one seen in the western Anatolia region. In this sub-region, there was a significant increase in the Tmean after 1980, while the variance remained unchanged.
- After 1980, the Tmean and its variability within the 10 stations representing Cluster 10 increased significantly.

Table 3. Clusters that emerged before and after 1980 for mean air temperature

Cluster no.	Region/sub-region
1	Humid temperate coastal Black Sea region
2	Dry sub-humid/semi-humid western Anatolia region
3	Dry sub-humid/semi-arid continental (larger) central Anatolia region
4	Dry sub-humid/semi-humid cold continental (larger) eastern Anatolia region
5	(Dry summer subtropical) semi-arid/dry sub-humid hot continental and dry sub-humid/semi-humid warm Mediterranean region
6	Semi-humid cold continental eastern Anatolia sub-region
7	Semi-humid Marmara transition sub-region
8	(Dry summer subtropical) humid warm coastal Mediterranean region
9	Dry sub-humid south-western transition (to central Anatolia) sub-region
10	Dry sub-humid/semi-humid continental central-east and inner eastern Black Sea transition (to the eastern Anatolia) sub-region

Table 4. Student's paired and Pitman-Morgan (P-M) *t*-test results for the common clusters obtained from the 'before' and 'after' 1980 periods for mean air temperatures (°C). *p < 0.05; **p < 0.1

Cluster no.	No. of stations	Average		SD		r	Paired *t*-test	P-M *t*-test
		Before	After	Before	After			
1	23	13.844	13.942	0.504	0.625	0.933	**0.062	*0.012
2	30	15.234	15.424	2.906	2.976	0.999	*0.000	*0.009
3	50	11.097	11.186	1.203	1.243	0.985	*0.006	0.199
4	27	9.266	9.597	3.208	3.239	0.996	*0.000	0.595
5	17	16.929	17.307	1.312	1.262	0.976	*0.000	0.499
6	22	8.843	9.089	2.327	2.274	0.993	*0.000	0.391
7	13	13.956	14.171	0.830	0.779	0.990	*0.000	0.160
8	12	18.743	18.981	0.584	0.572	0.859	*0.004	0.907
9	13	18.654	18.868	0.503	0.530	0.777	*0.045	0.787
10	10	9.288	9.416	0.998	1.057	0.980	**0.092	*0.012

4.2.2. Tmax patterns

There were slight differences in the clusters regarding average Tmax when we compare the results of the 2 periods as shown in Fig. 5. The clusters/regions that emerged are presented in Table 5, and are stated below.

- One of the most important changes that occurred after 1980 was that Cluster 7 appeared. Pazar station, located on the coastal eastern Black Sea, was the only common station during the whole period in this sub-region.
- Before 1980, Malazgirt in eastern Anatolia and Milas station in south-western Anatolia showed the same climate characteristics as Pazar station, but after 1980, Malazgirt station became more similar to the continental eastern Anatolia, while Milas became a part of the western Anatolia region.
- After 1980, Cluster 1 became smaller and Cluster 4 became wider, while the other regions seemed to remain the same in 2 periods.

To uncover any possible differences in the clusters before and after 1980, we applied the paired *t*-test and P-M *t*-test; results are shown in Table 6 for the common stations of each cluster (see also Figs. 6 & 7). Some statistically significant inferences are as follows:

- For the Tmax, the mean difference was not significant for Clusters 1, 6 and 8, whereas for the other regions, there were significant increases.
- When changes in variability were considered, it was evident that only the variance of Cluster 1 changed significantly.
- Since there was only one common station (i.e. Pazar) in Cluster 7, the differences in the mean and variance of the Tmax for the 2 periods could not be tested.

4.2.3 Tmin patterns

The geographical patterns of the average Tmin clusters obtained for the 2 periods differed considerably from the geographical patterns of the average Tmax and Tmean clusters of the 2 periods (see Fig. 5). The changes in the cluster patterns of the average Tmin were greater than those of the other air temperature series. These changes can be seen in Fig. 5. The clusters that emerged are given in Table 7, and described below.

- In the first period, Cluster 1 was represented by the humid temperate mid and eastern coastal Black Sea region, while in the second period, Cluster 1 was represented by the humid temperate coastal Black Sea region as in the Tmean and Tmax patterns. In other words, after 1980, the general char-

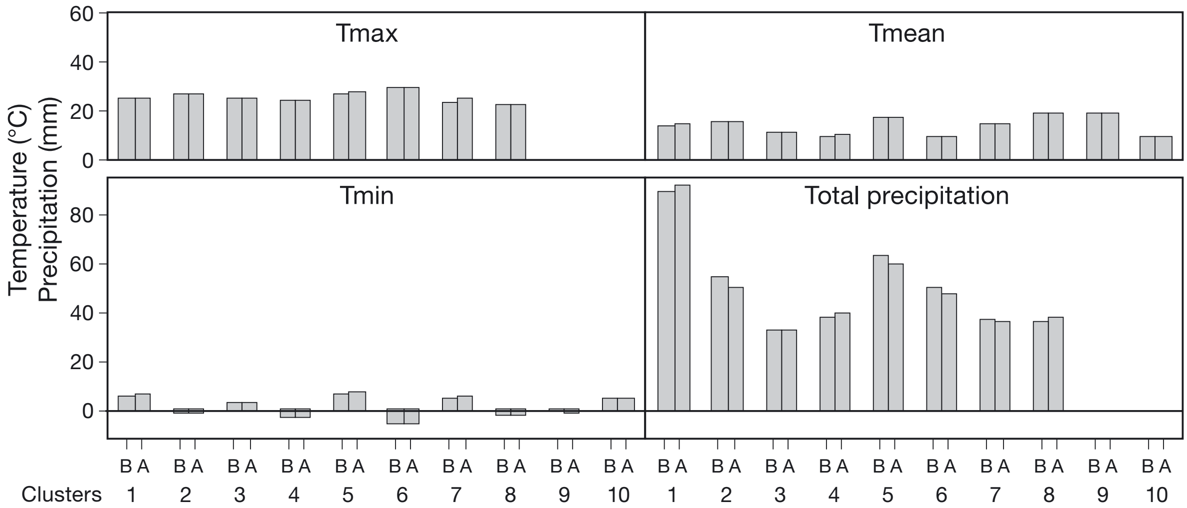

Fig. 6. Long-term averages of air temperatures and total precipitation variables calculated before (B) and after (A) 1980 for each cluster separately

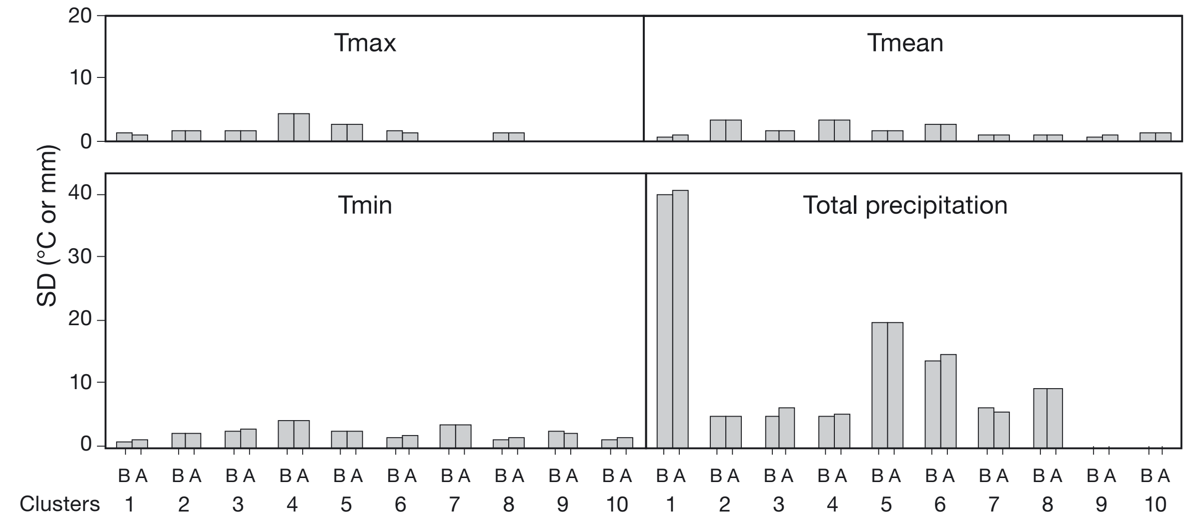

Fig. 7. Standard deviations of air temperatures and total precipitation variables calculated before (B) and after (A) 1980 for each cluster separately

acteristic of the humid temperate Black Sea climate dominated the semi-humid/humid temperate eastern Marmara transition (to the Black Sea) subregion, which was associated with Cluster 10. However, the Tmin of both regions did not reveal any significant trend or change in terms of either average or SD.

- There was also a marked change in the geographical pattern of the Cluster 2 climate region. The main part of this region became narrower, and the south-eastern part of continental central Anatolia (referred to as Cluster 8) became wider after 1980, but in this case within the Cluster 6 sub-region.
- It was evident that the Tmin characteristics of some parts of continental central Anatolia changed to Cluster 8.
- Some parts of Cluster 3 and Cluster 7 with 13 stations, referred to as Cluster 9, became a part of the continental central Anatolia region.
- As in the other regions of Turkey, the Tmin pattern did not change considerably after 1980.

Below are some statistically significant inferences made based on the test results given in Table 8 (see also Figs. 6 & 7).

- The average Tmin increased significantly in Clusters 2–8.
- The variance increased significantly only in Clusters 3 and 6.

Table 5. Clusters that emerged before and after 1980 for maximum air temperature

Cluster no.	Region/sub-region
1	Humid temperate coastal Black Sea region
2	Semi-humid central/eastern Marmara transition (to Black Sea) sub-region
3	Dry sub-humid/semi-arid continental (larger) central Anatolia region
4	Continental (larger) eastern Anatolia region
5	Dry sub-humid/semi-humid warm western Anatolia and humid western Mediterranean region
6	Semi-humid/humid hot eastern Mediterranean sub-region
7	Humid temperate eastern coast Black Sea sub-region
8	Dry sub-humid/semi-humid continental central-east and inner eastern Black Sea transition (to the eastern Anatolia) sub-region

Table 6. Student's paired and Pitman-Morgan (P-M) *t*-test results for the common clusters obtained from the before and after 1980 periods for maximum air temperatures (°C). $^*p < 0.05$

Cluster no.	No. of stations	Average Before	Average After	SD Before	SD After	r	Paired *t*-test	P-M *t*-test
1	10	25.283	25.247	0.858	0.581	0.884	0.801	*0.041
2	17	26.346	26.771	1.400	1.299	0.973	*0.000	0.226
3	58	24.722	25.010	1.369	1.408	0.975	*0.000	0.354
4	64	23.748	24.139	4.071	4.061	0.994	*0.000	0.856
5	61	27.042	27.394	2.500	2.439	0.990	*0.000	0.186
6	13	29.411	29.549	1.283	1.132	0.957	0.221	0.181
7	1	23.426	24.974	–	–	–	–	–
8	9	22.398	22.615	0.872	0.922	0.823	0.260	0.804

Table 7. Clusters that emerged before and after 1980 for minimum air temperature

Cluster no.	Region/sub-region
1	Humid temperate coastal Black Sea region
2	Semi-arid/dry sub-humid continental central Anatolia region
3	Dry sub-humid/semi-humid Thrace (northern Marmara) sub-region
4	Dry sub-humid/semi-humid continental cold (larger) eastern Anatolia region
5	(Dry summer subtropical) semi-humid/humid eastern Mediterranean and semi-arid/dry sub-humid continental Mediterranean region
6	Dry sub-humid continental cold central Anatolia transition (to eastern Anatolia) sub-region
7	Dry sub-humid/semi-humid warm western Anatolia and humid western Mediterranean region
8	Semi-arid/dry sub-humid continental southern central Anatolia transition (to the warm and continental Mediterranean) sub-region
9	Central north-western Anatolia transition (to the western Anatolia) sub-region
10	Semi-humid/humid temperate eastern Marmara transition (to the Black Sea) sub-region

4.2.4. Precipitation amounts

The patterns of precipitation regions obtained for the 2 periods given in Fig. 5 were obviously different from each other. The clusters that emerged are shown in Table 9 and defined below.

- The major change in terms of precipitation was seen in the central Anatolia region, where the *k*-means and hierarchical clustering results differed substantially (see also Fig. 4).
- Based on the *k*-means method,

– The central Anatolia region was split into 2 parts as the precipitation regions of the continental central-west Anatolia region and continental central-east Anatolia region during the whole time series from 1950–2010.

– North-west Turkey (i.e. the Marmara and western Anatolia region), Cluster 5 of south-western Anatolia and the coastal Mediterranean region previously defined by Türkeş & Tatlı (2011) could be seen.

- Based on the hierarchical clustering method,

– Although the continental central-west Anatolia region and continental central-east Anatolia precipitation regions existed before 1980, afterwards, these regions combined into a single cluster as the geographical pattern of Cluster 7, which was renamed the larger continental central Anatolia region, and revealed the same precipitation characteristics.

– While the total precipitation amount in the central-west Anatolia decreased, the total precipitation amount increased in the central-east after 1980.

– After 1980, Cluster 2 became smaller and the humid Black Sea region became wider by gaining areas from north-west Turkey.

– After 1980, a distinct precipitation regime (Cluster 8), within con-

Table 8. Student's paired and Pitman-Morgan (P-M) *t*-test results for the common clusters obtained from the before and after 1980 periods for minimum air temperatures (°C). *p < 0.05; **p < 0.10

Cluster no.	No. of stations	Average Before	Average After	SD Before	SD After	r	Paired *t*-test	P-M *t*-test
1	13	6.027	6.148	0.828	0.993	0.933	0.263	0.119
2	34	−1.447	−1.264	1.897	1.946	0.956	**0.073	0.629
3	9	3.164	3.284	2.462	2.662	0.995	*0.021	**0.077
4	46	−3.474	−3.066	3.952	3.934	0.978	*0.000	0.881
5	30	6.789	7.389	2.398	2.425	0.953	*0.000	0.842
6	12	−5.972	−5.502	1.336	1.825	0.941	*0.046	*0.014
7	48	4.821	5.287	3.347	3.455	0.988	*0.000	0.173
8	14	−2.454	−2.092	1.095	1.203	0.903	*0.021	0.461
9	13	−0.893	−1.002	2.440	2.155	0.968	0.570	0.127
10	12	4.795	5.042	1.104	1.269	0.916	0.124	0.294

Table 9. Clusters that emerged before and after 1980 for total precipitation

Cluster no.	Region/sub-region
1	Humid temperate (larger) coastal Black Sea region
2	North-west Turkey (Marmara and western Anatolia region together)
3	Continental central and central-east Anatolia region
4	Continental north and eastern Anatolia region
5	South-western Anatolia and coastal Mediterranean region (the 'real' Mediterranean precipitation regime region in Turkey)
6	Continental Mediterranean and eastern-south Anatolia region
7	Continental central-west Anatolia region (precipitation regimes 3 and 7 together form the combined [larger] continental central Anatolia region)
8	Continental rainy summer north-eastern Anatolia sub-region

Table 10. Student's paired and Pitman-Morgan (P-M) *t*-test results for the common clusters obtained from the before and after 1980 periods for total precipitation (mm). *p < 0.05; **p < 0.10

Cluster no.	No. of stations	Before average	After average	Before SD	After SD	r	Paired *t*-test	P-M *t*-test
1	22	89.790	92.480	39.810	40.690	0.998	*0.000	0.134
2	29	54.572	50.382	4.878	4.631	0.889	*0.000	0.556
3	30	32.485	33.050	4.600	6.170	0.901	0.289	*0.001
4	12	37.550	39.450	4.620	5.060	0.718	**0.100	0.682
5	35	62.940	60.190	19.620	19.760	0.987	*0.000	0.792
6	35	50.500	47.720	13.700	14.600	0.963	*0.000	0.185
7	26	37.370	36.330	6.140	5.260	0.887	**0.075	0.113
8	10	36.250	37.560	9.130	9.090	0.987	*0.021	0.938

tinental north and eastern Anatolia appeared. The total precipitation in this new region was lower than that of the rest of the continental north and eastern Anatolia region.

– Some of the eastern part of the eastern-south Anatolia region became a part of the continental north and eastern Anatolia precipitation region as a result of a decrease in total precipitation amount.

Results obtained by testing the differences in the mean and variance of total precipitation amounts using the common stations for each cluster are given in Table 10 (see also Figs. 6 &7). Below are some statistically significant inferences made based on these results.

- There were significant differences in means for all clusters except Cluster 3.
- The means of the total precipitation amounts increased significantly in Clusters 1, 4 and 8 after 1980, and decreased significantly in north-west Turkey.
- A significant change in the variance of total precipitation was only seen in Cluster 3, and the variability characteristic increased significantly after 1980.

5. DISCUSSION

In terms of the air temperature series, the continental central Anatolia region became wider in the period after 1980, even though this region is divided into 2 sub-regions based on the minimum temperature series. There was an increase in all the temperature series of all the regions. The approximate average increases after 1980 were 0.19°C (13.11–12.92°C) in the Tmean, 0.33°C (25.71–25.38°C) in the Tmax and 0.34°C (1.63–1.29°C) in the Tmin series (Table 2, Fig. 6). These results provide evidence the air temperature in Turkey has increased, and are strongly concordant with the significant increases in the Tmean, Tmax and Tmin in most of Turkey and in the Eastern Mediterranean Basin detected by Türkeş et al. (2002), Türkeş & Sümer (2004), Türkeş (2013), Erlat & Türkeş (2012, 2013) and Kuglitsch et al. (2010), respectively.

The variability in the air temperature series for common stations did not show much change. A significant increase in the variance of the Tmean series was obtained for the humid temperate coastal Black Sea (Cluster 1) and the dry summer western Anatolia (Cluster 2) regions (see Figs. 5 & 7, Table 4). Also, an increase in the variance of the Tmin series occurred in the northern Marmara sub-region (Cluster 3) and continental cold central Anatolia transition sub-region (Cluster 6) (Figs. 5 & 7, Table 8). A significant decrease in the variance of the Tmax series was seen only for the humid temperate coastal Black Sea region (Cluster 1) (Figs. 5 & 7, Table 6).

The total precipitation amounts changed markedly from region to region in Turkey: in some regions the precipitation amount increased, whereas in others it decreased. For the following interpretations, refer to Figs. 5 & 6 and Table 10. After 1980 (when compared to before 1980), the greatest decrease in the regionally averaged precipitation amount was seen in the Aegean region (Cluster 2) at about 4.2 mm (54.572–50.382 mm). Both the continental Mediterranean (Cluster 6) and the 'real' Mediterranean precipitation (Cluster 5) regions experienced significant decreases at about 2.8 mm. Also, in the continental central-west Anatolia region (Cluster 7), the average precipitation amounts decreased at about 1 mm. On the other hand, the largest increase in the regionally averaged precipitation amount was seen in the coastal Black Sea region (Cluster 1) at about 2.7 mm, followed by the continental north and eastern Anatolia region (Cluster 4) and continental north-eastern Anatolia (Cluster 8) at about 1.9 and 1.3 mm, respectively.

The geographical patterns of the Turkish precipitation regions changed considerably after 1980. These results, depicting precipitation decreases observed particularly in the western and southern regions of Turkey which are mainly characterized by a Mediterranean climate, correspond well with the results pointed out for Turkey by Sönmez & Kömüşcü (2011), Türkeş (1996, 1998, 1999, 2011, 2013), Türkeş & Altan (2013) and Türkeş et al. (2009a,b).

While there were 2 different precipitation regimes in continental central Anatolia before 1980, they combined into a single, larger cluster (Cluster 7) after 1980 as a result of a decrease in total precipitation in the west and an increase in the east of the continental central Anatolia region (Cluster 3). Another important difference was the appearance of a new precipitation region after 1980, namely the continental rainy summer north-eastern Anatolia sub-region (Cluster 8) within the continental north and eastern Anatolia region (Cluster 4). In this region (Cluster 8), there was a significant decrease in the total precipitation amount compared to the rest of the continental north and eastern Anatolia region (Cluster 4); however, the observed change in variability was not significant. On the other hand, in the continental central-east Anatolia region (Cluster 3), the variance of total precipitation indicated a significant increase.

The numbers and spatial distribution patterns of the climate and precipitation regions and subregions in Turkey found in the present study showed good agreement with those detected using Ward hierarchical and *k*-means clustering methods (e.g. Fahmi et al. 2011, Kartal et al. 2011, Türkeş & Tatlı 2011, Sahin & Cigizoglu 2012, Iyigun et al. 2013), and weak agreement and less similarity with the results of Unal et al. (2003).

6. CONCLUSIONS AND FURTHER RESEARCH

In the present study, the climate regions of Turkey and the changes in their geographical patterns in terms of mean and variance characteristics were determined for the mean, maximum and minimum air temperature series and the total precipitation series using 2 consecutive time periods: 1950–1980 and 1981–2010. To achieve this, *k*-means and Ward hierarchical clustering methods were used to determine the climate regions, and both methods suggested the same number of climate regions for each variable for the air temperature and precipitation regions. We then compared these climate regions in terms of both the differences in period means with the paired *t*-test and the differences in period variances with the P-M *t*-test for common stations observed in both periods within the same region.

The semi-arid and dry sub-humid continental central Anatolia climate characteristics expanded substantially, while the semi-humid and humid temperate coastal climate regions became narrower. This significant change was evaluated to be a very likely indicator of drought risk for most of Turkey — not only under the present climate, but in the future climate as well. This result could also be considered as clear evidence of the impact of observed climate change and variability in Turkey. Consequently, we suggest that this significant indicator of change in the

Turkish climate be taken into account by policy makers, public and private sector institutes and universities, representatives of the socioeconomic sectors and non-governmental environmental organizations, and ecological movements and organizations.

In terms of further study, additional climatological variables such as atmospheric humidity, evapotranspiration, and cloudiness could be added to the analyses, and their relationship considered in terms of climate change and variability. The effect of urbanization and air pollutants could also be considered in the cluster analyses to uncover any human-induced impact on the Turkish climate. Moreover, the characteristics of temperature and precipitation could be evaluated via principal component analysis and singular spectrum analysis as suggested by Benzi et al. (1997). The selected clustering methods could also be extended via their fuzzy versions (e.g. Liu & George 2003, 2005, Plain et al. 2008, Horenko 2010) and kernel methods (e.g. Sap & Awan 2005) to take into account any variation in the analysis due to the spatiotemporal nature of such a dataset.

Acknowledgements. This study was supported by a BAP Project of the Middle East Technical University (METU), Ankara, Turkey, under contract number BAP-2008-01-09-02. The authors express their gratitude to all members of the NINLIL research group, www.stat.metu.edu.tr/, for their contributions. The authors also thank Gary Conlan (School of Foreign Languages, METU, Turkey) for assessment of the language qualification of our manuscript.

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Editorial responsibility: Eduardo Zorita, Geesthacht, Germany

Submitted: August 10, 2015; Accepted: June 19, 2016
Proofs received from author(s): September 19, 2016