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ORIGINAL PAPER

Clustering current climate regions of Turkey by using a multivariate statistical method

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Abstract In this study, the hierarchical clustering technique, called Ward method, was applied for grouping common features of air temperature series, precipitation total and relative humidity series of 244 stations in Turkey. Results of clustering exhibited the impact of physical geographical features of Turkey, such as topography, orography, land–sea distribution and the high Anatolian peninsula on the geographical variability. Based on the monthly series of nine climatological observations recorded for the period of 1970–2010, 12 and 14 clusters of climate zones are determined. However, from the comparative analyses, it is decided that 14 clusters represent the climate of Turkey more realistically. These clusters are named as (1) Dry Summer Subtropical Semihumid Coastal Aegean Region; (2) Dry-Subhumid Mid-Western Anatolia Region; (3 and 4) Dry Summer Subtropical Humid Coastal Mediterranean region [(3) West coast Mediterranean and (4) Eastern Mediterranean sub-regions]; (5) Semihumid Eastern Marmara Transition Sub-region; (6) Dry Summer Subtropical Semihumid/Semiarid Continental Mediterranean region; (7) Semihumid Cold Continental Eastern Anatolia region; (8) Dry-subhumid/Semiarid Continental Central Anatolia Region; (9 and 10) Mid-latitude Humid Temperate Coastal Black Sea Region [(9) West Coast Black Sea and (10) East Coast Black Sea sub-regions]; (11) Semihumid Western Marmara Transition Sub-region; (12) Semihumid Continental Central to Eastern Anatolia Sub-region; (13) Rainy Summer Semihumid Cold Continental Northeastern Anatolia Sub-region; and (14) Semihumid Continental Mediterranean to Eastern Anatolia Transition Sub-region. We believe that this study can be considered as a reference for the other climate-related researches of Turkey, and can be useful for the detection of Turkish climate regions, which are obtained by a long-term time course dataset having many meteorological variables.

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1 Introduction and literature review

Climate has been evolving since the existence of the Earth because of some internal and external factors as well as the enforcements that were given rise by the human being. Climate change, on the other hand, is portrayed as "statistically significant changes in the average state of the climate or in its variability state continued for dozens of years" (Türkeş 2008a, b). Another crucial description in this framework is the "climate variability." The climate variability represents the changes in meteorological variables' center (e.g. average) and spread (e.g. standard deviation) through time and within the land scales in junction with the changes in other statistics such as the occurrence of extreme events (Türkeş 2011). The climate variability can occur depending on the natural internal factors within the climate system or the changes in the natural external and enforced effects (Türkeş 2008a, b). During the geological history of the Earth's climate system, there occurred many alterations because of natural causes and forcings. In addition to these natural changes in climate, human-originated factors and forcings are observed for the first time that affect climate beginning from the industrial revolution. Since then, in addition to the natural variability in the climate, a new period where the human activities also affect the climate has started for the first time. Therefore, nowadays, climate changes can be defined by considering the influence of human activities which lead to the increase in greenhouse gas in the atmosphere, also called global warming (Türkeş 2008a, 2011). As a result of this, rise in global surface temperatures followed by the alteration in hydrological cycle, a shift in climate belts, the occurrence of more frequent and severe heat waves, extreme rains in some regions and severe drought are expected, which lead to cause major changes directly affecting human life and ecological systems (Intergovernmental Panel on Climate Change (IPCC) 2001, 2007).

Identifying climate regions of a country is very important because knowledge of climate has a wide range of uses. Solar and wind energy-related strategies or policies on regional water management planning can be developed; areas appropriate for farming and type of animals inhabiting in that area can be identified. Also, understanding the current climate zones can give valuable information about the changes in the climate in time. The scientific studies on the global climate basically examine the changes in both climate and components of climate as well as the reasons lying behind these changes (e.g. Chung et al. 2004; Freiwan and Kadioglu 2008; Liepet 1997; Norrant and Douguedroit 2006; Trigo et al. 2006; Türkeş and Erlat 2003, 2005, 2008, etc.), in addition, the effects of these changes on both hydrology (e.g., Burn and Hag Elnur 2002; Chaponniere and Smakhtin 2006; Melack et al. 1997) and flora (e.g. Atlas of the Middle East 1993; Yılmaz 1998; De Castro et al. 2007; Piccarreta et al. 2004; Prasada et al. 2008, etc.). Other studies on global climate include redefinition of the climate regions and/or rainfall regime regions that have been formed as a result of the ongoing climate change (e.g. Alijani et al. 2008; Malmgren and Winter 1999; Mimmack et al. 2000, 2001; De Gaetano 1996; Fovell 1997; Fovell and Fovell 1993; Türkeş 1996, 1998, 2003; Türkeş and Tatli 2011; Türkeş et al. 2009a).

Turkey is located between mid-latitude temperate climate zone and subtropical climate zone. Because of the high and diverse topography, Turkey has many different climate regimes. Basically, the climate of Turkey is a Mediterranean-type macro-climate. Turkey stands in the risk group in terms of the potential effects of climate change and global warming (Altınsoy et al. 2011; Sen et al. 2012; Türkeş 2008a, 2011; Türkeş 2011, etc.). The studies showed that there exists a tendency of increase in the average annual and seasonal surface temperature as well as the temperature at night for the last 15 years, while a decrease in the number of days with frost (e.g. Türkeş et al. 2002a; Türkeş and Sümer 2004, etc.). Moreover, in the series of long-term precipitation, especially in winter and yearly series, a decreasing tendency (drying) starting from early 1970s is dominant (Türkeş 1996, 1998, 1999; Türkeş and Erlat 2005; Türkeş et al. 2009a, etc.). In a different study in which the trends and changes in the number of frost days were investigated, Erlat and Türkeş (2012) found that the annual number of frost days has evidently decreased at most of the stations in Turkey with some observed regional differences. The decreasing trends are largest over the Eastern Anatolia, the Marmara regions and along the Mediterranean coastline. Kömüşçü (1998) reported that the change in climate of Turkey has not been realized randomly; on the contrary, it displays variations in respect to particular periods. Tayanç and Toros (1997) have observed the effect of urbanization on precipitation and temperature and have found the relation between the urbanization and the increase in the temperature.

It is well known that the precipitation and evaporation are two components playing a crucial role in the climate system. Accordingly, the water balance in a region can be supplied by controlling these two variables (Türkeş et al. 2009b; Türkeş and Tatli 2011, etc.). The spatial variation of precipitation is important to understand the features of precipitation of Turkey, which have different types of climates and conditions of physical geography (Türkeş et al. 2009b). Kadıoğlu and Şen (1998) and Aslantaş and Akyürek (2007) indicated an increase in the number of rainy days between the years 1961 and 1990, and in the amount of rain in coastal regions between the years 1970 and 2003, respectively. (Tatlı et al. 2004) found that there were local effects in inner regions of Turkey, whereas in coastal regions, the large-scale pressure systems and the high atmospheric circulation were in effect, hereby strong rainfalls were observed in the Black Sea Region. Partal and Kahya (2006) have declared an increase in the precipitation in Central Anatolia and a decline in precipitation in January, February, and September. Aksoy et al. (2007) have presented that, in Turkey, the precipitations decline while the temperature raises, and in the future, severe weather events such as flood and drought can be seen.

Method of clustering has been applied in many studies to define climate regions in the world. For instance, in the study of Stooksbury and Michaels (1990), the climate regions for eight southeastern states in the USA were determined by a two-step clustering analysis performed on 449 climate stations. Fovell and Fovell (1993), on the other hand, identified the climate zones of conterminous USA by using a hierarchical cluster analysis based on temperature and precipitation data consisting of 24 variables including monthly surface air temperature means and precipitation totals over the 50-year period between 1931 and 1980. On the other side, in the study of Gaffen and Ross (1999), a modified version of the eight-cluster solution was considered to analyse the trends in USA air, humidity and temperature, and De Gaetano (1996) defined the climate regions within the northeastern USA by a combined analysis of two multivariate techniques, namely, principle component and clustering analysis. A similar classification scheme was studied for India and West Africa as well (e.g. Gadgil and Joshi 1983; Anyadike 1987, etc.). Finally, Fovell (1997) clustered temperature and precipitation data separately and identified the climate zones by a consensus clustering that can determine the temperature sub-zones on precipitation clusters (or vice versa), and represented distinct groupings, which are relatively homogeneous with respect to both types of attributes simultaneously. Whereas, different from other studies, Steinbach et al. (2003) performed clustering to analyse the effect of oceans and atmosphere on land climate by developing a climate index. Also, Akal et al. (2012) used clustering techniques to detect the impact of climate change on seasons.

As for Turkey, we have been using the seven climate zones, which had been identified by taking into account not only the climate differences but also the changes in the social and economic properties of the country from 1960s to 2000s (Erinç 1984; Koçman 1993; Türkeş 2003, etc.). After years, one of the studies dealing with the climate regions of Turkey was done by Ünal et al. (2003). In this work, five different hierarchical clustering methods, namely, single, complete, centroid and average linkage as well as the Ward's minimum variance clustering analysis were performed for air temperature (mean, minimum and maximum) and total precipitation variables. But for the detection of the climate regions, merely the findings of the Ward method have been considered. Later, Türkeş and Tatli (2011) implemented the spectral clustering method for the classification of the Turkish precipitation series. In this study, the results were also evaluated by considering the previous findings given in Türkeş (1996, 1998), Türkeş et al. (2002b), Türkeş and Tatli (2009) and Türkeş et al. (2009a) in conjunction with the cluster results based on the atmospheric and physical geographical controls. Here, the interpretation of the climate regions was presented from two to eight plausible clusters. Moreover, Fahmi et al. (2011) studied the climate zones of Turkey via the center-based clustering methods based on monthly air temperature data of 65 stations for the period of 1950–2006. From their analysis by k-means and fuzzy clustering methods, five clusters were found as acceptable. As an extension of this study, the hierarchical clustering methods have also been applied by including seven air temperature and one precipitation variables (Kartal et al. 2011). In this extended analysis, a more comprehensive dataset has been taken into account via 220 stations for the period 1970 to 2006. Finally, by using a different approach, in two consecutive 30-year periods, the climate of Turkey was determined by the Ward's minimum variance clustering method, and the resulting changes are examined. For this purpose, precipitation data obtained from 247 stations for the period 1950–2010 were used.

Depending on these findings, due to the impact of climate change and variability on Turkey, and due to the lack of an agreement on the definition of climate regions of Turkey until now, in this study, we aimed at ideally redefining climate regions of Turkey by hierarchical clustering method using almost all usable station data over Turkey with a larger number of meteorological variables. In addition, in this study, among the possible different climate regions which may occur as a result of using different clustering methods, "the best defined climate regions" are going to be exposed with detailed climatologic comments and argumentation.

This paper is organized as follows: Global and regional importance of the climate and climate change and variability and purpose of the study along with a review of literatures that covers studies for identifying climate zones were given in Section 1. In Section 2, the description of data and the methodology applied in the analysis are described. Results and their geographical/climatological synthesis are presented in Section 3. In Section 4, the findings of the study are given, and finally, the concluding remarks and further studies are briefly stated.

2 Data and methodology

2.1 Data description and preprocessing

The dataset used in this study includes nine variables, namely, monthly mean, minimum, and maximum surface air temperatures, monthly minimums of mean temperatures, monthly maximums of mean temperatures, monthly averages of minimum temperatures, monthly averages of maximum temperatures, monthly precipitation totals (in millimeters) and monthly relative humidity (in per cent) recorded at 244 stations of the Turkish State Meteorological Service (TSMS) over the period 1970–2010 (Fig. 1).

Before conducting any statistical analysis, data preprocessing was carefully applied. There exist many missing observations in the series. Especially, precipitation series is the most challenging one. If the precipitation amount is 0.1 mm or less, the value is recorded as zero to the database by TSMS, but no value is entered if there is no precipitation at all in a specific month. If the value is missing (i.e. not recorded due to any reason), then there is also no data entry in the database. To be able to identify if a value is missing or no precipitation is recorded at all, a detailed discriminative analysis was conducted. For this purpose, when the precipitation value of a month for a specific station is not entered, the values of the neighbouring stations, data entry for temperature series and the values of the same month in different

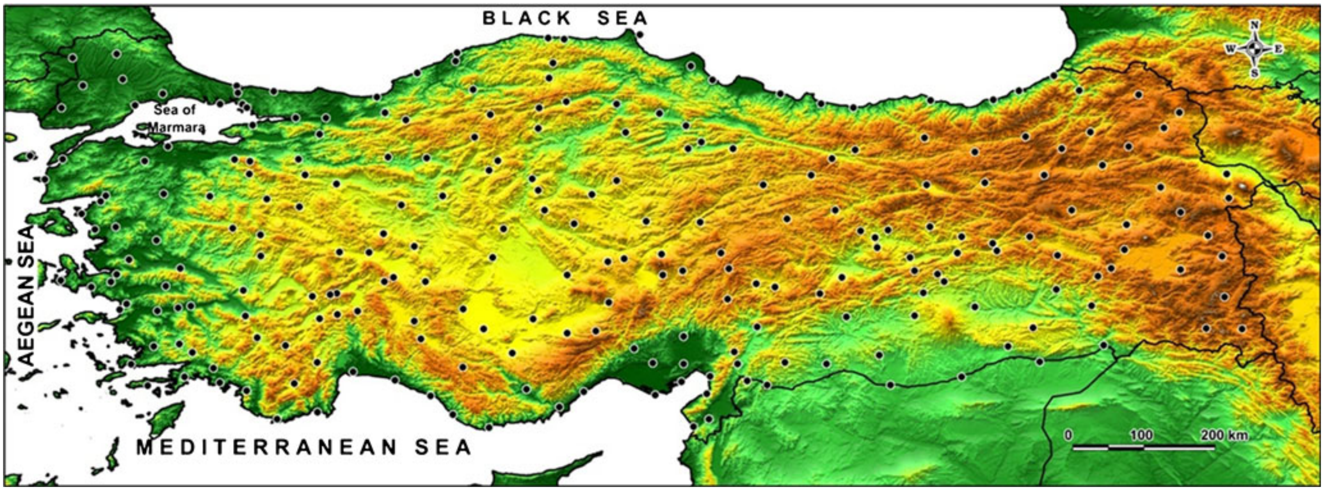

Fig. 1 Spatial distribution of 244 meteorological stations over Turkey used in the study

years are controlled. Then, the value was entered as zero if it was decided to that there was no precipitation for that month or kept as missing. By this analysis, 18 % of the precipitation data were entered, hence gained to the database as the value zero.

Although there are 270 active climate stations all over Turkey, due to missing observations and homogeneity problems, most of the researchers have had to use only a few number of stations or relatively short time period of data (Şen and Habib 2001a, b; Türkeş 1996, 1998, 1999; Türkeş et al. 2002b, 2009a; Türkeş and Sümer 2004; Türkeş and Erlat 2003, 2005, 2008, 2009 and Ünal et al. 2003). Recently, Aslan et al. (2010) and Yozgatligil et al. (2012) investigated the missing data problem by searching for the most suitable imputation method(s) applied on the meteorological data. Six imputation methods are used and evaluated with respect to various criteria including accuracy, robustness, precision and efficiency for artificially created missing data in monthly total precipitation and mean temperature series in seven regions with different climatologic characteristics. These methods were simple arithmetic average, normal ratio (NR) and NR weighted with correlations, multi-layer perceptron-type neural network and multiple imputation strategy adopted by Monte Carlo Markov Chain based on expectation-maximization (EM-MCMC). It has been concluded that the EM-MCMC method is the most appropriate one compared to the others. Depending on this result, in our study, all missing values for the nine variables were imputed by EM-MCMC method for at most 50 % missing series. The information from the stations with more than 50 % of missing data was not used. With the help of this imputation technique, we could be able to cover the highest number of stations which represent the climate of Turkey very well. As far as the authors' knowledge, this is the first study using this many stations' information related to the climate of Turkey by now. We believe that because the study covers a very large spatial distribution of Turkey, the clustering results may be more reliable.

In the clustering, different variables were decided to be used representing the climate zones of Turkey. However, the ranges of these variables are different from each other, so the information provided by each variable is different (see Table 1). As a result, the precipitation variable which has the highest range may dominate the clustering results. To overcome this problem, all the variables were standardized such that they had zero mean and unit variance. In the standardization procedure, the monthly averages and standard deviations were used. After the standardization, clustering method was applied to all nine variables.

2.2 Clustering analysis

Cluster analysis is an effective statistical tool used in many climatic and atmospheric studies, especially for determining homogeneous climate regions based on meteorological variables. A long list of such studies is given in Section 1. By clustering, objects with the similar proximity are assigned

Table 1 Ranges of the monthly climatological variables used in the study

Variables	Minimum	Maximum
Maximum air temperature (°C)	−16.4	50.0
Average of maximum air temperature (°C)	−18.2	45.6
Minimum air temperature (°C)	−45.6	27.0
Average of minimum air temperature (°C)	−27.9	28.7
Mean air temperature (°C)	−21.3	37.3
Maximum of mean air temperature (C)	−9.5	41.6
Minimum of mean air temperature (°C)	−40.3	33.6
Total precipitation amount (mm)	0.0	907.2
Relative humidity (%)	0.0	99.5

into the same group, while dissimilar objects are allocated into different clusters. The proximity between objects is determined according to a distance measure, such as *Euclidean*, *Manhattan*, or *Mahalanobis*, whereas the distance measure which is commonly used in many atmospheric studies is the Euclidean distance.

Unlike other commonly used multivariate statistical analyses, cluster analysis does not require any assumptions regarding the data distribution. However, as stated above, the data should be preprocessed by standardization if the scale of one variable is significantly different from those of the others. Otherwise, a variable measured in larger units can dominate the others.

In studies of climate and atmospheric sciences, with respect to the problems of interest, several methods of cluster analysis are used under the name of hierarchical and non-hierarchical methods. Since hierarchical methods are useful for exploratory purposes, they are preferred in many studies related to the determination of climate regions (e.g. Fovell and Fovell 1993; Ünal et al. 2003; Estrada et al. 2009, etc.); hereby the same approach is also adopted in the analysis of this study. In addition, a similar study with more climatological/meteorological variables recorded at larger number stations (220) of Turkey was carried out by Kartal et al. (2011). The present study is an extension of their study, which includes the implementation of Ward's method to nine climatological/meteorological variables (seven temperature variables, precipitation and relative humidity), collected between the years 1970 and 2010 from 244 stations. Moreover, a large number of climatological records with missing observations are imputed by an effective approach, called EM-MCMC (Yozgatligil et al. 2012). Therefore, results obtained by Ward's method are expected to be more reliable and realistic than the results obtained by Kartal et al. (2011), in which mean imputation is used.

2.3 A hierarchical clustering algorithm: the Ward's method

Hierarchical clustering algorithms are among the fundamental clustering methods that are not only grouping the data into particular clusters represented by centers but also performing a series of partitioning or merging on the clusters so that a hierarchical structure of dataset can be built. Briefly, in hierarchical algorithms, the clustering is depicted by a tree-like diagram as given in Fig. 2, called a *dendogram* (Jardine and Sibson 1971). The root of a dendogram represents a single cluster containing all observations (i.e. data points), and each leaf is regarded as an individual observation. Hereby, in the middle of the tree, child clusters partition the point attached to their common parents via a similarity (proximity) measure. The height of the dendogram usually reveals the distance between each pair of data points or clusters, or a data points and a cluster (Xu and Wunsch 2009). The final clustering is obtained by cutting the dendogram at different levels. This way of clustering usually provides a good representation of cluster structures within data which includes a real hierarchical relation such as evolutionary research on species of organism or applications in archaeology, biology and geography (Everitt et al. 2001; Theodoridis and Koutroumbas 2006).

The hierarchical clustering methods are generally categorized into two major approaches, namely, *agglomerative*, where one starts at the leaves and successively merges clusters together; and *divisive*, in which we can begin with the root and recursively split the clusters (Jain and Dubes 1988; Kaufman and Rousseeuw 1990). Since divisive methods are computationally more intensive than agglomerative methods, agglomerative methods are more widely preferred in applications. The general steps of the agglomerative clustering can be summarized as follows:

1. Start with N singleton clusters, and calculate proximity matrix for the N clusters.
2. In the proximity matrix, search for the minimal distance $D(C_i, C_j) = \underset{1\leq m,l\leq N, l\neq m}{m\,\text{in}} D(C_A, C_B)$, where $D(.,.)$ represents the distance measure and combine cluster C_i and C_j to form a new cluster C_{ij}.
3. Update the proximity matrix by computing the distances between the clusters C_{ij} and the other clusters.
4. Repeat steps 2 and 3 until only one cluster remains.

Moreover, for agglomerative hierarchical techniques, a large number of proximity measures, also called linkage metrics, can be defined between two clusters. Some of these measures are single linkage, complete linkage, average linkage and Ward's method (Xu and Wunsch 2009; Everitt et al. 2001; Jain and Dubes 1988). In single linkage, the distance between a pair of clusters is determined by two closest objects to the different clusters. Opposite to the idea of the single linkage similarity, the complete linkage uses the farthest distance of a pair of objects to define inter-cluster distance. It is an effective method for uncovering small and compact clusters. Moreover, in the average linkage, the distance between two clusters is defined as the average of the distance between all pairs of data points, each of which comes from different groups. Finally, the Ward's method (Ward 1963) combines a pair of clusters by minimizing the amount of increase in the sum of squares (SS) when they are merged:

$$\nabla(C_A, C_B) = \sum_{i\in A\cup B} \|\boldsymbol{x}_i - \boldsymbol{m}_{A\cup B}\|^2 - \sum_{i\in A} \|\boldsymbol{x}_i - \boldsymbol{m}_A\|^2 - \sum_{i\in B} \|\boldsymbol{x}_i - \boldsymbol{m}_B\|^2 = \frac{n_A n_B}{n_A + n_B} \|\boldsymbol{m}_A - \boldsymbol{m}_B\|^2, \quad (1)$$

where, $\mathbf{m}_j$ is the center and n_j is the number of data points in cluster j. Here, $\|.\|$ represents the Euclidean

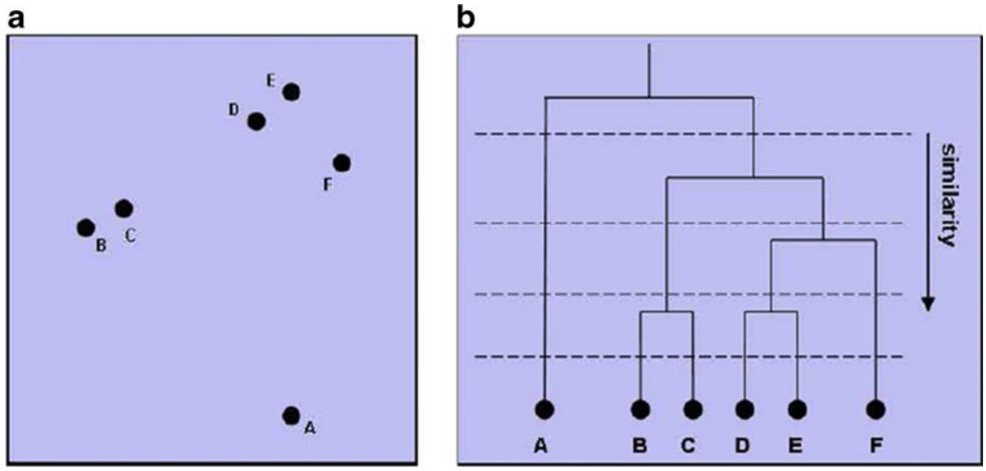

Fig. 2 The row dataset is shown in (**a**) and its dendogram from the hierarchical clustering is illustrated in (**b**), where the *dashed lines* present different partitioning at different levels of similarity

distance, and ∇ is the merging cost of combining the clusters *A* and *B*. In Ward's method since every point is in its own cluster, SS starts at zero and then grows as the clusters are merged. Note that the method keeps this growth as small as possible.

The main advantage of hierarchical clustering methods is that the number of clusters is not determined beforehand. Since a complete hierarchy of clusters is computed and visualized by a dendogram, one can define the clusters by stopping the partition at different levels. However, this flexibility may lead to different clustering interpretations with different number of clusters. Under such cases, the usual practice is that a large disparity in the levels of dendogram, at which clusters merge, can be accepted as the indication of the natural groupings, whereas different heuristics may be also used to unravel this uncertainty. For example, as suggested by Jain (1986), selection of the dissimilarity value can be performed in such a way that the dendogram can be built by a large gap between different clusters. Alternatively, as implemented by Halkidi et al. (2001), various validity indices and their graphical representations at different stages of the partition can be used to determine where to prune the tree structure in the hierarchical clustering.

The common disadvantage of classical hierarchical clustering algorithms, however, is its high computational complexity, especially for large-scale datasets. In order to address this problem and other disadvantages, some new hierarchical clustering algorithms have also been proposed such as Balanced Iterative Reducing and Clustering using Hierarchies, known as BIRCH (Zhang et al. 1997) and Clustering Using Representatives, known as CURE (Guha et al. 1998).

3 Results and their geographical/climatological synthesis

Although we have considered and plotted all resultant cluster patterns from the Ward methodology, we have chosen and interpreted here only the 12 and 14 number of clusters because they gave the most reasonable results in terms of the existing climatological, atmospheric and physical geographical features and conditions. In other words, the number of clusters is validated by subject evaluation of a domain expert judgment. The proposed names of the climate regions, their basic properties and the number of stations in each region can be seen in Table 2. A summary of basic features of the determined climate regions/sub-regions was also prepared by taking into consideration the results and interpretations of the previous studies performed mainly by Erinç (1984), Koçman (1993), Atalay (2002), Kutiel et al. (2001), Saris et al. (2010), Türkeş (1996, 1998, 1999, 2003, 2010), Türkeş and Erlat (2003, 2005, 2006, 2008, 2009), Türkeş and Tatli (2009, 2011) and Türkeş et al. (2009a).

When spatially coherent large climate regions are considered, it is seen that, with 52 stations, Dry-subhumid/Semiarid Continental Central Anatolia region (cluster 7 and cluster 8 in Fig. 3a and b, respectively) has the largest area which can be described as dry forests and large steppe lands over the large plains, plateaus and highlands dominating over the Central Anatolia region of Turkey. Dominant climate types of Turkey can be recognized as dry summer subtropical semihumid and humid in the coastal Aegean and Mediterranean regions, and partly in the continental Mediterranean region; dry-subhumid and partly semiarid in the mid-western and Continental Central Anatolia regions; semihumid cold and continental in the Eastern Anatolia region, continental central to Eastern Anatolia sub-region, the Northeastern Anatolia sub-region and continental Mediterranean to Eastern Anatolia transition sub-region; and finally, mid-latitude humid temperate on the coastal Black Sea region (Fig. 3a, b).

On the other hand, there are two basic differences between the spatial patterns of the cluster 12 and cluster 14. When 14 clusters are used, Dry-summer Subtropical Humid Coastal Mediterranean region is divided into two parts as the West Coast Mediterranean Sub-region and the Eastern

Table 2 Contemporary climate regions and sub-regions of Turkey according to the resultant 14 clusters of the Ward clustering methodology, and their basic physiographic, climatological and meteorological characteristics

Climate region/climate sub-region	Summary of the basic physiographic, climatological and meteorological characteristics	Number of stations
(1) Dry Summer Subtropical Semihumid Coastal Aegean Region	Subtropical Semihumid mesothermal coastal Aegean climate characterized mostly with natural vegetation formations of the Mediterranean forests [e.g. pines (*Pinus brutia*, *Pinus nigra*, etc.), oaks (e.g. *Quercus cerris*, *Quercus infectoria*, *Quercus ithaburensis* subsp. *macrolepis*, etc.] and maquis, and largely the native trees of olive (*Olea europaea*), which of its most attractive characteristic is high seasonality with a maximum winter precipitation and a minimum summer precipitation with high surface air and sea temperatures.	25
(2) Dry-Subhumid Mid-Western Anatolia Region	Transition region from semihumid Aegean and humid Mediterranean to the dry-subhumid/semiarid continental Central Anatolia region	32
(3 and 4) Dry Summer Subtropical Humid Coastal Mediterranean Region	Dry Summer subtropical humid and hot coastal Mediterranean climate, which is the macroclimate mainly, results from the seasonal alternation between mid-latitude (frontal) cyclones, associated with polar air masses, during the winter and subtropical high pressure systems, from subsiding maritime and continental tropical air masses during the summer. Its most attractive characteristic is also of high seasonality with a maximum winter precipitation and a minimum summer precipitation with hot surface air and sea temperatures. Consequently, it is mostly characterized with natural vegetation formations of the Mediterranean forests (e.g. pines, oaks, *Cupressus sempervirens*, etc.) and maquis, etc.	25
(3) West coast Mediterranean Sub-region	'Real' Mediterranean climate with a maximum winter precipitation and hot and dry long-summer season mainly associated with the large scale weather systems and influenced by their seasonal and inter-annual variations.	12
(4) Eastern Mediterranean Sub-region	'Real' Mediterranean climate but having more local topographic and regional circulation influences such as tropical monsoon circulation in summer and continental northerly circulation in winter.	13
(5) Semihumid Eastern Marmara Transition Sub-region	Semihumid mesothermal transition climate in the Eastern Marmara sub-region developing mainly between the Mediterranean and the Black Sea climate regions, which is characterized mainly with vegetation of mixed or pure dry forests (both conifers and broad-leaved deciduous, mainly red pine and oaks) and maquis.	12
(6) Dry Summer Subtropical Semihumid/ Semiarid Continental Mediterranean Region	Dry summer subtropical semihumid and semiarid hot continental Mediterranean climate, vegetation of which is mostly characterized with dry forests and steppe.	18
(7) Semihumid Cold Continental Eastern Anatolia Region	Semihumid microthermal Continental Eastern Anatolia climate, characteristic vegetation formations of which are of mostly dry and mixed forests, meadow and steppe lands over the high plains, plateaus and mountains.	18
(8) Dry-subhumid/ Semiarid Continental Central Anatolia Region	Dry-subhumid and semiarid mesothermal and microthermal Continental Central Anatolia climate, which is mostly characterized with dry forests and large steppe lands over the large plains, plateaus and highlands.	52
(9 and 10) Mid-latitude Humid Temperate Coastal Black Sea Region	Humid and perhumid temperate climate occur on the Turkish Black Sea coastal belt, except the Black Sea coast of the Marmara Region, with a plenty of precipitation in all seasons with a maximum amount in autumn, occurrence of which is associated with mainly mid-latitude cyclones and orographical lifting of the polar (particularly maritime and somewhat continental) air masses forced by northerly circulation on the northern windward slopes of the Northern Anatolia Mountains coming through the Black Sea, and characterized with the vegetation of humid boreal mixed (both conifers and broad-leaved deciduous) forests.	18
(9) West Coast Black Sea Sub-region	Distribution of precipitation over a year is relatively steady. Over the years, the variability of precipitation is low.	8
(10) East Coast Black Sea Sub-region	Although the yearly precipitation totals are high, and within a year the distribution of precipitation is relatively regular, year-to-year variability of precipitation is high. The East Coast Black Sea climate is also more temperate than the West Coast Black Sea climate.	10
(11) Semihumid Western Marmara Transition Sub-region	Semihumid mesothermal transition climate in the Western Marmara sub-region, which is more continental than the Eastern Marmara. It is also a transition climate between the Mediterranean climate and both the Black Sea and more continental Balkans Peninsula climates. It is characterized mainly with vegetation of mixed dry forests (both conifers and broad-leaved deciduous, mainly red pine and oaks), maquis, and steppes.	8

Table 2 (continued)

Climate region/climate sub-region	Summary of the basic physiographic, climatological and meteorological characteristics	Number of stations
(12) Semihumid Continental Central to Eastern Anatolia Sub-region	Semihumid mesothermal and microthermal Continental Central to Eastern Anatolia Transition climate.	11
(13) Rainy Summer Semihumid Cold Continental Northeastern Anatolia Sub-region	Semihumid microthermal Continental Northeastern Anatolia climate is dominant over the more continental and higher plateaus and mountainously areas of the Eastern Anatolia region of Turkey, along with the vegetation formations of mostly dry and coniferous forests, meadow and steppe.	8
(14) Semihumid Continental Mediterranean to Eastern Anatolia Transition Sub-region	Semihumid mesothermal Continental Mediterranean to Eastern Anatolia Transition climate is mostly characterized with the vegetation formations of dry forests and steppe.	17

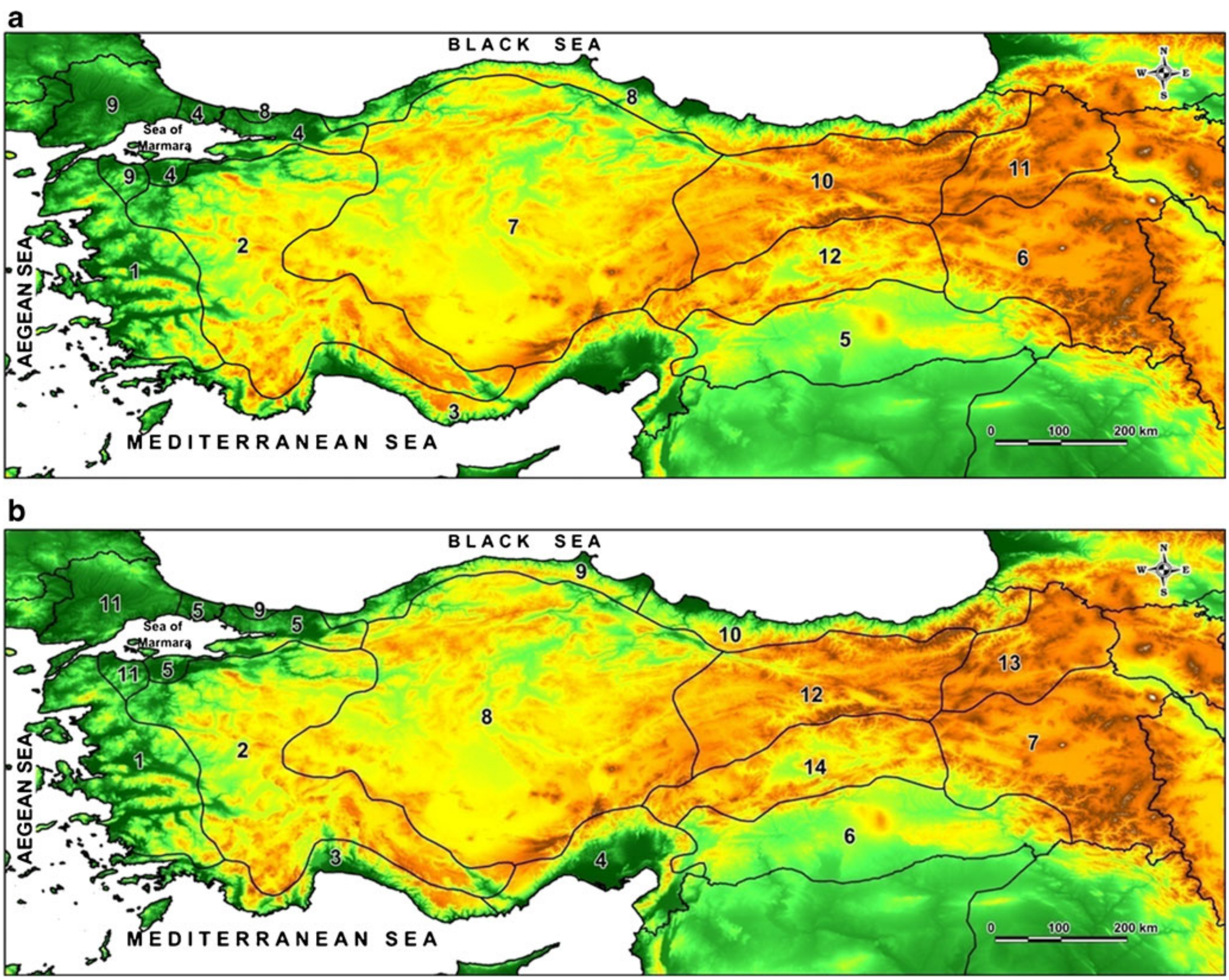

Fig. 3 Climate regions of Turkey, zonation of which was arranged by using the Ward method and generalized for 12 (**a**) and 14 (**b**) clusters. Names of the climate regions and sub-regions according to the 14 clusters are as follows: (*1*) Dry Summer Subtropical Semihumid Coastal Aegean; (*2*) Subhumid Mid-Western Anatolia; (*3* and *4*) Dry Summer Subtropical Humid Coastal Mediterranean [(*3*) West Coast Mediterranean and (*4*) Eastern Mediterranean]; (*5*) Semihumid Eastern Marmara Transition; (*6*) Dry Summer Subtropical Semihumid/Semiarid Continental Mediterranean; (*7*) Semihumid Cold Continental Eastern Anatolia; (*8*) Dry-subhumid/Semiarid Continental Central Anatolia; (*9* and *10*) Mid-latitude Humid Temperate Coastal Black Sea [(*9*) West Coast Black Sea and (*10*) East Coast Black Sea]; (*11*) Semihumid Western Marmara Transition; (*12*) Semihumid Continental Central to Eastern Anatolia; (*13*) Rainy Summer Semihumid Cold Continental Northeastern Anatolia; (*14*) Semihumid Continental Mediterranean to Eastern Anatolia Transition

Mediterranean Sub-region. Both regions have the Mediterranean climate, but eastern part has more local topographic and regional circulation influences. Similarly, the Mid-latitude Humid Temperate Coastal Black Sea Region is divided into two parts as the West Coast Black Sea Sub-Region and the East Coast Black Sea Sub-Region. The main difference in characteristics of these regions is their annual and interannual precipitation and humidity regimes. For instance, even though yearly distribution of precipitation is relatively steady and the year-to-year precipitation variability is lower in the West Coast Black Sea climate sub-region, the yearly precipitation totals and the interannual precipitation variability are evidently higher in the East Coast Black Sea climate sub-region (Türkeş 1996, 1998, 1999, 2003; Türkeş and Tatli 2009; Türkeş et al. 2002b). The East Coast Black Sea climate is also more temperate than the West Coast Black Sea climate (Türkeş 1999, 2010).

4 Conclusion and further research

Earth is our home planet, and without its perfect combination of chemicals, there is no life for any animal and plant. Determination of climate regions of a country is very important to understand the basic features of the geographical environment. Without knowing the climate of a certain region, agricultural, forestry and hydrological strategies cannot be developed. To be able to do climate-related analyses like detection of a climate change and its possible effects, working on datasets in homogeneous groups gives more meaningful results (Sneyers 1990; Türkeş and Tatli 2011, etc.). Clustering is one of the methods to decide those homogeneous groups. In this study, a hierarchical clustering method, called Ward's method, was applied to determine the climate regions of Turkey using several temperature series, precipitation totals and relative humidity. To detect the climate zones of Turkey, among many alternatives, we implemented the hierarchical clustering approach based on the Ward's method because of its simplicity in the interpretation of the results and consistency with the climatological/meteorological knowledge about the zones.

In this paper, we use the monthly Turkish meteorological data taken from TSMS recorded in the period between 1970 and 2010 for capturing the general features of the climate in Turkey. The dataset whose missing observations are imputed by the EM-MCMC method includes 244 stations with nine variables which are composed of seven air temperature (listed as mean, minimum, maximum surface air temperature, minimum of mean temperature, maximum of mean temperature, average of minimum temperature and average of maximum temperature), precipitation totals and relative humidity.

Hereby from the analysis, we observe 12 climate regions whose atmospheric and physical as well as geographical properties are supported by the previous studies (Erinç 1984; Koçman 1993; Türkeş 1996, 1998, 1999, 2010; Kutiel et al. 2001; Türkeş et al. 2002b; Türkeş and Erlat 2003, 2005, 2006, 2008, 2009; Tatlı et al. 2004; Türkeş et al. 2009a). Moreover, from the assessment of spatial patterns of climate regions we find that the dry-subhumid/semiarid continental Central Anatolia climate zone, denoted by item 8 in Table 2, with 52 stations presents the largest climate area and mainly dominates over the continental central part of Turkey. Briefly, this climate region indicates dry forests and large steppe lands over the large plains, plateaus and highlands. Thereby, it can represent a risky area for drought in the future, and the national authorities can consider some precautions to overcome this challenge by examining the continental inland regions. Furthermore, from the outputs, we see that the influence of sea on coastal parts can be observed easily but on a limited region, and this outcome can be helpful for the policy makers to develop new strategies on agriculture, forestry and natural resources management including soil and water, etc.

We believe that the generated climate groups in Table 2 can be considered as reference and one of the major researches on the detailed and multi-variable climate types in Turkey for other researches related to the climatology, climate planning, climate change and climate variability in Turkey. From our main findings, it is also seen that the final climate types of Turkey well capture the climatological knowledge in the literature and successfully explains the features of each climate zone. Therefore, we believe that this study can be useful for the detection of Turkish climate regions, which are obtained by a long-term most homogeneous and continuous dataset having many meteorological variables. On the other hand, for example according to Türkeş (2010) and Türkeş and Tatli (2009, 2011), the main implications of these kinds of studies performed for determining the precipitation regimes/regions and climate types/regions may give the various researchers, planners and decision makers a strong facility and a unique chance for understanding and planning their hydrological and hydro-climatological systems and water resources including drinking waters, groundwater, rivers, hydroelectric production, forestry, agricultural and irrigation activities and others. Finally, we also believe that redefining climate regions of Turkey with contemporary and effective statistical techniques will constitute an important contribution and benefit for the accomplishment of Turkey's responsibility on the scope of the United Nations Climate Change Convention and Kyoto Protocol, and all climate-related national and regional-scale planning and management studies and activities.

As an extension of this study, we plan to add more climatological variables into the analysis in order to improve the current results further. Also, the duration of the data can be extended to cover a longer period of time. Moreover, in the current findings, we consider merely the temporal effect of the data which can successfully validate the known geographical and climatological conditions of the climate zones, whereas the same measurements can be included for clustering under both their temporal and spatial features. Determining the number of climate regions with time series data using clustering validation techniques (see Volkovich et al. (2008) for some recent results) is another and important research direction for future studies. Furthermore, different clustering approaches can be applied under the multivariate, rather than univariate, dimension in such a way that the pattern recognition methods can be implemented to ensemble different variables. Additionally, the ecological varieties can be used as covariates to this clustering by considering the climatological changes which can also be seen via changes in the ecological diversity. To the best of our knowledge, such a detailed clustering of ecosystem types has not been yet done in Turkish data apart from certain regional studies (Yılmaz 1998) or major land uses of Turkey (Atlas of the Middle East 1993).

Moreover, the idea of clustering can be considered as a model-based approach which enables us to predict the future values of stations via gene–environment network (see Weber et al. 2009; Defterli et al. 2011; Defterli et al. 2012. Under such modeling, time course data throughout the years for each station combined with the environmental factors such as water vapour, solar variations, volcanic activity or growing populations can be described as a system of ordinary differential equations and can be solved via non-linear programming.

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