INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **23**: 1045–1055 (2003)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/joc.910

REDEFINING THE CLIMATE ZONES OF TURKEY USING CLUSTER ANALYSIS

YURDANUR UNAL,[a,*] TAYFUN KINDAP[b] and MEHMET KARACA[b,c]
[a] *ITU, Department of Meteorology, 80626 Maslak Istanbul, Turkey*
[b] *ITU, Eurasia Institute of Earth Sciences, 80626 Maslak Istanbul, Turkey*
[c] *ITU, Maden Fak. Department of Geology, 80626 Maslak Istanbul, Turkey*

Received 19 September 2001
Revised 16 February 2003
Accepted 3 March 2003

ABSTRACT

Climate zones of Turkey are redefined by using the mathematical methodology of cluster analysis. Data from 113 climate stations for temperatures (mean, maximum and minimum) and total precipitation from 1951 to 1998 are used after standardizing with zero mean and unit variance, to confirm that all variables are weighted equally in the cluster analysis. Hierarchical cluster analysis is chosen to perform the regionalization. Five different techniques were applied initially to decide the most suitable method for the region. Stability of the clusters is also tested. It is decided that Ward's method is the most likely to yield acceptable results in this particular case, as is often the case in climatological research. Seven different climate zones are found, as in conventional climate zones, but with considerable differences at the boundaries. Copyright © 2003 Royal Meteorological Society.

KEY WORDS: cluster analysis; climate zones; Turkey

1. INTRODUCTION

Many climatological studies have used a variety of data to define climatic types and delineate zones of similar climate. Several methods have also been applied for the climatic zones. The most famous examples are the Koeppen and Thornthwaite classifications. A principal advantage of these approaches is that they directly and quantitatively specify the climate types. A disadvantage is that the classification rules are subjectively formulated, and thus open to question.

In this study, an alternative approach including cluster analysis methodology has been used. Cluster analysis applied to meteorological variables is a suitable approach for redefining the climate divisions, and its use is becoming increasingly more common in atmospheric research (Kalkstein *et al*., 1987; Fovell and Fovell, 1993).

Choosing appropriate data to cluster is an initial consideration in cluster analysis. In climate classification, the variability of long-term precipitation and temperature data are the most readily available variables (Fovell and Fovell, 1993).

The seven climate zones over Turkey, shown in Figure 1, are those that have conventionally been accepted by Turkish climatologists since the beginning of the 20th century (Erinç, 1984):

1. The Black Sea region.
2. The Marmara region.
3. The Aegean region.

* Correspondence to: Yurdanur Unal, ITU, Department of Meteorology, 80626 Maslak Istanbul, Turkey; e-mail: sunal@itu.edu.tr

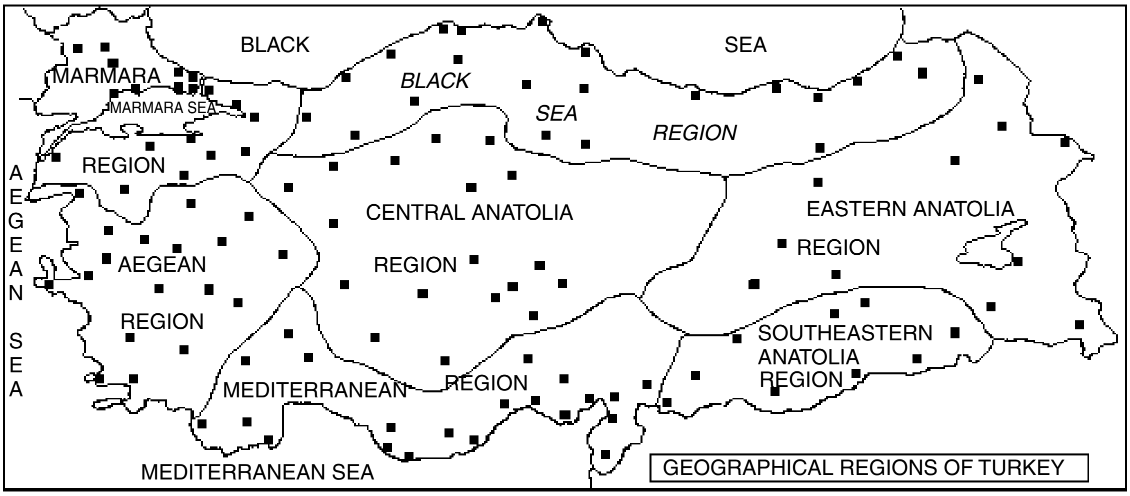

Figure 1. Conventional classification of climate zones and distribution of data in Turkey

4. The Mediterranean region.
5. The central Anatolian region.
6. The eastern Anatolian region.
7. The southeastern Anatolian region.

All these regions are defined in qualitative terms, not quantitatively. This zone classification has been used not only for differences in climate but also for social and economic variables.

There have been several quantitative attempts by Türkeş and co-workers (Türkeş *et al.*, 1995; Türkeş, 1996, 2000) to classify the climate zones based on the variations of coefficients of temperature and precipitation. There are many contradictory results in these studies. Despite the flexibility of the methods used by them, we think that their pictures for climate zones are somewhat misleading for a definition of the climate zones for Turkey. For example, the wettest regions were found in the far eastern Black Sea region (Rize and Hopa) and at Bitlis, which is located in the high plateau region of eastern Turkey. There is nothing in common between these three stations in terms of their local climates. Two of them are near the Black Sea and the other (Bitlis) is in the high plateau of eastern Turkey. This difference is probably due to their use of the Thornthwaite method. For the classification based on the temperature field, the temperature stations in the northeastern part of Turkey (Artvin, Kars and Erzurum) behaved differently to the rest of the stations.

All these regions are defined in a qualitative way, not quantitatively. In this study we intend to define spatially homogeneous climate regions of Turkey by using a mathematical methodology called cluster analysis.

2. CLIMATE DATA

The meteorological variables selected in the development of the homogeneous clusters are monthly average, maximum and minimum temperatures, and monthly total precipitation. This selection of variables ensures that groups with common climatic conditions can be identified seasonally, regionally and by elevation. Monthly data were obtained from the National Weather Service of Turkey in digitized format and span the period of January 1951 to December 1998. There are 287 station data in the initial data set. The list of stations is given in Table 1 with their altitude. We use the homogeneity analysis techniques proposed by Karaca *et al.* (1995), and tested by Tayanç *et al.* (1998). For example, when we apply these techniques to the stations the climate data of Antalya is not homogeneous due to the relocation of the station in 1974. The annual temperature change from 1951 to 1998 given in Figure 2 shows the problem clearly. There is a bogus drop in the year 1975.

Table I. The list of all stations and their altitudes

Name	Longitude	Latitude	Altitude (m)	Name	Longitude	Latitude	Altitude (m)
Bandırma	27,58	40,21	58	Diyarbakır	40,14	37,54	677
Bursa	29,04	40,11	100	Islahiye	36,38	37,02	518
Balıkesir	27,53	39,38	3	Bingöl	40,29	38,53	1177
Dikili	26,53	39,04	3	Adıyaman	38,17	37,45	672
Akhisar	27,51	38,55	93	Hakkari	43,44	37,35	1728
Manisa	27,26	38,37	71	Kilis	37,07	36,43	638
Uşak	29,24	38,41	919	Batman	41,07	37,53	540
İzmir	27,10	38,26	25	Ergani	39,46	38,17	1000
Aydın	27,51	37,51	57	Nusaybin	41,13	37,14	500
Bodrum	27,06	37,03	27	Erzincan	39,30	39,45	1215
Muğla	28,22	37,13	646	Erzurum	41,16	39,55	1869
Fethiye	29,07	36,37	3	Ağrı	43,03	39,43	1632
Kütahya	29,58	39,25	969	Van	43,23	38,30	1725
Çanakkale	40,09	26,25	6	Kars	43,06	40,37	1775
Denizli	37,47	29,05	426	Iğdır	44,03	39,55	858
Finike	30,42	36,53	3	Ardahan	42,43	41,07	1829
Edremit	27,01	39,36	21	Bayburt	40,14	40,15	1584
Simav	28,59	39,05	809	Bolu	31,31	40,44	742
Ödemiş	27,58	38,14	118	Kastamonu	33,47	41,22	799
Nazilli	28,19	37,55	60	Merzifon	35,20	40,52	755
Elmalı	29,55	36,45	1095	Çorum	34,57	40,33	837
Çeşme	26,18	38,19	5	Sivas	37,01	39,45	1285
Keles	29,04	39,55	1063	Bilecik	29,59	40,09	526
Selçuk	27,22	37,57	17	Yozgat	34,48	39,49	1298
Edirne	26,34	41,40	48	Afyon	30,32	38,45	1034
Tekirdağ	27,33	40,59	3	Kayseri	35,29	38,44	1068
Kireçburnu	29,03	41,10	56	Burdur	30,17	37,43	967
Göztepe	29,05	40,58	33	Isparta	30,33	37,46	997
Kocaeli	29,56	40,47	76	Konya	32,29	37,52	1026
Lüleburgaz	27,21	41,24	46	Niğde	34,41	37,58	1208
Şile	30,25	40,47	83	Eskişehir	30,31	39,49	801
Florya	28,45	40,59	36	Ankara	32,53	39,57	890
Kırklareli	27,14	41,44	232	Çankırı	33,37	40,36	751
Çorlu	27,48	41,10	183	Amasya	35,5	40,39	412
Kumköy	29,02	41,15	30	Tokat	36,34	40,18	608
Sakarya	30,25	40,47	31	Esenboğa	33,00	40,08	949
Kartal	29,11	40,54	28	Kırşehir	34,10	39,09	1007
Yalova	29,16	40,39	4	Nevşehir	34,40	38,35	1260
Anamur	32,50	36,05	5	Kızılcahamam	32,39	40,28	1033
Mersin	34,36	36,48	3	Sivrihisar	31,32	39,27	1070
Adana	35,20	37,00	20	Akşehir	31,25	38,21	1002
İskenderun	36,10	36,25	4	Beyşehir	31,43	37,41	1129
Dörtyol	36,13	36,51	28	Ulukışla	34,29	37,33	1453
Antakya	36,10	36,12	100	Karaman	33,13	37,11	1025
Alanya	32,30	36,33	7	Ürgüp	34,55	38,38	1060
Silifke	33,56	36,23	15	Tomarza	35,29	38,44	1347
Mut	33,26	36,39	275	Zonguldak	31,48	41,27	136
Gazipaşa	32,19	36,16	21	İnebolu	33,46	41,59	64
Yumurtalık	35,47	36,46	27	Sinop	35,10	42,01	32
Karataş	35,23	36,34	22	Samsun	36,18	41,17	4
Malatya	38,19	38,21	998	Giresun	38,24	40,55	37
Elazğd	39,14	38,40	991	Trabzon	39,43	41,00	31
Siirt	41,57	37,55	896	Rize	40,31	41,02	4
Gaziantep	37,23	37,04	840	Artvin	41,49	41,11	597
Şanlıurfa	38,46	37,08	549	Hopa	41,26	41,24	33
Mardin	40,44	37,18	1080	Bozkurt	33,47	41,22	167
Amasra	32,23	41,45	73				

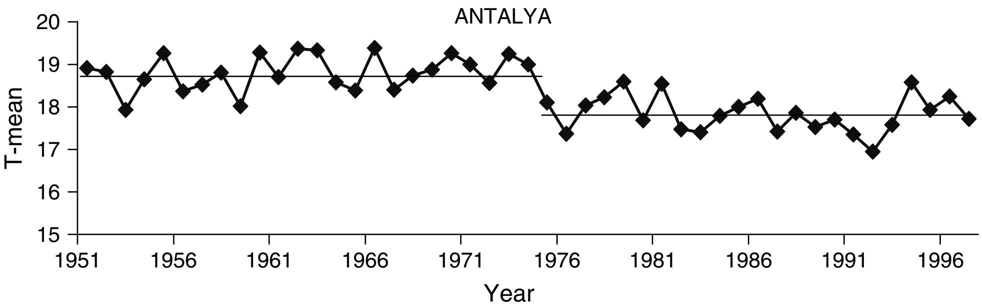

Figure 2. Annual temperature in Antalya from 1951 to 1998 (solid lines show the mean values)

After identifying the stations with the longest and most complete records, carefully scrutinizing and quality controlling these data, it is concluded that only 113 of them are suitable for analyzing spatial and temporal variations over Turkey. This subset has no more than 20% of missing values, and 61 of them have no missing values. Then, 36 temperature and 12 precipitation variables are standardized to zero mean and unit variance, to confirm that all variables are weighted equally in the cluster analysis.

3. METHODOLOGY

Cluster analysis is an effective statistical tool to find homogeneous climate zones based upon observed values of meteorological parameters. Unlike other commonly used statistical methods, cluster analysis is not based on some theoretical *a priori* assumed distribution. Therefore, care must be taken in the choice of all clustering methods. Methods of cluster analysis are widely used in different types of problem in atmospheric research. It can be performed by hierarchical and non-hierarchical techniques. However, hierarchical clustering methods are ideal for the exploratory stage of research. They require specific measurements of dissimilarity to characterize the relationships among the stations and to search for the most similar station pairs to merge. Two common metrics for cluster analysis are distance measures and correlation coefficients. Euclidean distance (the square root of the sum of the squared distances over all variables) is the most common distance metric used in atmospheric sciences. Although the use of correlation coefficients can provide an alternative metric, one of their drawbacks is their lack of sensitivity to the magnitude of the differences between the variables. The hierarchical methods differ in how the distance between entries is calculated and how the two closest entries are defined. Since each algorithm uses slightly different criteria for forming clusters, the number and types of cluster formed can be different. However, all the hierarchical methods follow the basic four-step routine below to find those subsets that are both homogeneous and well separated, so that objects within the same cluster should resemble each other and objects in different clusters should differ from one another:

1. The specified distance measure between all entries (climate stations) is calculated.
2. The two closest entries are merged to form a new cluster based on a defined criterion.
3. The distance between all entries is recalculated.
4. Steps 2 and 3 are repeated until all entries are merged into one cluster.

There are five commonly used hierarchical clustering methods: single linkage, complete linkage, centroid, Ward's minimum variance and the average distance method. The simplest hierarchical clustering method is single linkage. In single linkage, the Euclidean distance between all entries in each cluster is compared. Although it has the advantage of being simple and straightforward, it has a problem with chaining. Complete linkage has been suggested as a technique to overcome the chaining tendency of single linkage. Although this method does overcome the chaining problem, it has been shown not to work in an *a priori* known cluster. The centroid method is the most robust of the commonly used hierarchical clustering methods, but it still suffers from the chaining problem (Milligan, 1980). The centroid method has been shown to produce one larger cluster and many small clusters when used in climatic research (Kalkstein *et al*., 1987).

Ward's minimum variance method has been the clustering technique most used in climate research (Kalkstein *et al*., 1987). It calculates the means of all variables within each cluster, then calculates the means of all variables within each cluster, then calculates the Euclidean distance to the cluster mean of each case, and finally sums across all cases. Ward's method has a tendency to form clusters of relatively small and equal numbers of objects. Climatic data has been shown to be sensitive to this problem of forming clusters of relatively equal size (Kalkstein *et al*., 1987). Since there is no reason to believe that the climate districts should have approximately the same number of stations, this is a major drawback of this technique. It has also been stated that single linkage, complete linkage and Ward's techniques perform very poorly under error perturbations (Milligan, 1980).

Average linkage overcomes many of the shortcomings of the other commonly used hierarchical methods. In average linkage, the distance is defined as the average Euclidean distance between pairs of entries. The average linkage method, unlike the single linkage and centroid methods, has a reduced tendency to form chains. Unlike Ward's technique, which minimizes the within-cluster sum of squared distances, average linkage minimizes within-group variance and maximizes between-group variance. It has been shown to give the most realistic results in climatological research (Kalkstein *et al*., 1987).

The dissimilarity measure applied here is the Euclidean distance. Each variable is standardized prior to distance calculation to eliminate the scale effect, since observations with different scales, such as temperature and precipitation, may unequally contribute to the calculated distance. Since there are missing values in our data set, we defined Euclidean distance as

$$d_{ij} = \frac{N}{M}\sum_{k=1}^{M}(x_{ik} - x_{jk})^2$$

where d_{ij} is the Euclidean distance between x_i and x_j over the M available data points. N is the number of data points in the full data period.

Therefore, the distances between stations are standardized by using the common period and the full period of 1951–98.

4. COMPARISON OF THE CLUSTER METHODS

The strengths and limitations of the several clustering methods must be understood to make an informed decision on which method is most suitable for a particular study. Therefore, several hierarchical clustering procedures–single linkage, complete linkage, average distance within clusters, average distance between clusters and Ward's method–were performed, and the resulting regionalizations of climate were compared to define the most suitable clustering algorithm for climatic variables over Turkey.

In cluster analysis, one of the main issues is to define the optimum number of clusters, i.e. at which step to terminate the clustering process. One way is to plot the minimum distances between the combined clusters versus the cluster numbers. This information can give guidance as to the optimal number of clusters. Sudden increases in the value of the distance reflect that the joining clusters are not very similar. Figure 3 shows the distances versus cluster numbers for the average distance between the cluster methods. There are jumps in the graph after four, six, eight and ten clusters. Here, by looking at the region, we decided to select the 8 cluster solution as an optimal solution for this case. Similarly we selected seven-, six-, six-, and seven-cluster solutions for single linkage, complete linkage, average distance within clusters, and Ward's methods respectively. Table II summarizes the number of stations within each cluster for all the clustering techniques.

It is clear that the single linkage technique assigns most of the stations (98 stations) into one cluster, showing the chaining problem, and there are three clusters with a single member. On the other hand, the complete linkage technique distributes the stations more evenly across the clusters. However, the Aegean, Mediterranean, southern Anatolia and southern part of the eastern Anatolian regions are all combined in

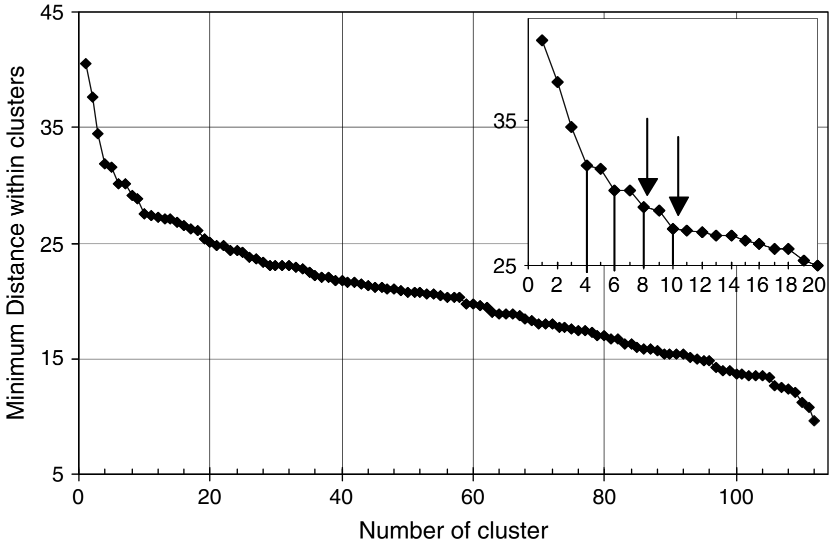

Figure 3. Sequence of similarities in which clusters merged for the average linkage between the clusters method. The arrows indicate preferred choices for the numbers of clusters at which to stop the clustering algorithm

Table II. Number of stations within each cluster for the applied cluster methods

Cluster method	A	B	C	D	E	F	G	H
Single linkage	5	98	3	1	1	4	1	
Complete linkage	16	51	3	32	2	9		
Average distance within	2	20	5	54	4	28		
Average distance between	6	27	39	26	4	6	1	4
Ward's method	15	12	24	14	8	29	11	

the same cluster. Ardahan, Kars and Kastamonu appear in the same cluster. Comparison of the annual temperature change of these stations reveals that Kastamonu cannot be in the same cluster as the others. Average temperatures in January, which is the coldest month, in Kars and Ardahan are −10.8 °C and −11.6 °C respectively, whereas the Kastamonu average January temperature is −0.9 °C for the time period 1951–98. July temperatures, which is the warmest month of all, on the other hand, are 13.5 °C, 12.7 °C and 17.3 °C in Kars, Ardahan and Kastamonu respectively. Average distance within the clusters method combines the Marmara and Aegean regions, and extends it towards the Central Anatolia region, but it also includes Samsun and Artvin in this cluster. On the other hand, the average distance between clusters and Ward's technique solutions seems more realistic.

To elucidate the solutions of the applied clustering techniques better, we calculated the serial correlations between the regionalized stations and cluster averages for the full period (Gong and Richman, 1995). Figure 4 shows these correlation coefficients for each variable and each method. The median, interquartiles and range of the correlation coefficients are marked. Single linkage has the worst correlations of all. The median of the biserial correlations is lower than the others for all variables. Cluster members in average distance between clusters and Ward's methods are comparable for all the variables. The range of the correlations in Ward's method is relatively large compared to the average distance between the clusters method, except for the maximum temperature. It gives, however, slightly higher medians. Therefore, the solution of either the average distance between the clusters or Ward's method is acceptable.

Finally, we tested both methods by using the smaller set of data to investigate the stability of the clusters. Therefore, we selected the subset with only 62 stations, in which each station has complete records in the

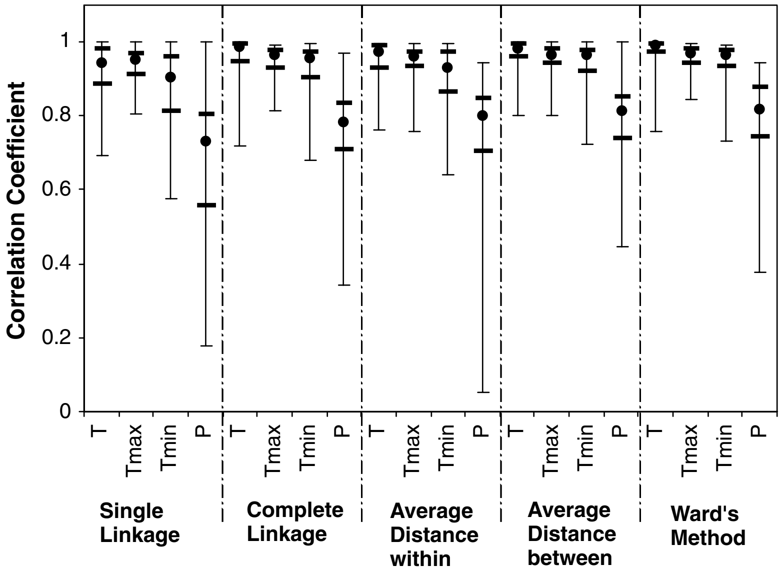

Figure 4. Biserial correlations between cluster average and regionalized stations' data in the same cluster for the full observation period. Circles represent the median; light dashes are interquartiles, with the range of the correlation coefficients

time span of interest. Small sets of data are clustered by using the average distance between merged clusters and Ward's methods. Figures are not shown. For both solutions, the same number of clusters are used, namely eight and seven for the average distance and Ward's methods respectively. Then, clusters of 62 stations are compared to the large data set solution.

In Ward's method, clusters of only 7 out of 62 stations changed. When this is compared with the clusters of the average distance method, station groupings reveal a more stable structure. For instance, Kütahya and Uşak in the central Anatolia cluster (which is similar to average distance) and Bandirma, Bursa and Balikesir in the Marmara region are combined with the Aegean cluster and result in an extension of the Aegean cluster into the central Anatolia region and south of Marmara. Islahiye, formerly in the Mediterranean cluster, shifted to the southern eastern Anatolia cluster and Erzincan from the southern eastern Anatolia cluster shifted to eastern Anatolia. In general, comparison of the cluster's stability between the subset and the full set shows that Ward's method gives consistent clusters in both cases. Therefore, we prefer to adopt Ward's method of cluster solution for further analysis.

5. CLUSTER SOLUTIONS USING WARD'S METHOD

The initial goal of this study is to determine, as objectively as possible, the climate zones of Turkey. Hierarchical cluster analysis is chosen to perform the regionalization. Single linkage, complete linkage, average linkage within a cluster and between clusters and Ward's techniques are used to decide the most suitable cluster analysis method for our purpose. It is decided that Ward's method is the most likely to yield acceptable results in this particular case, as is so often found in climatological research.

In our study, the result of Ward's clustering method indicates that four, seven or ten are appropriate numbers of classes. Even though there is no universally accepted objective method to decide on the number of clusters to be retained, seven classes are sufficient, in our opinion, to present the range of meteorological conditions, and the four- or ten-class solutions are either robust or detailed for our study, since they either combine many climatologically different sites into the same group or create very diverse clusters. Also, when we checked the previous solutions, it was seen to be too early to stop, because the Mediterranean region and the southeastern

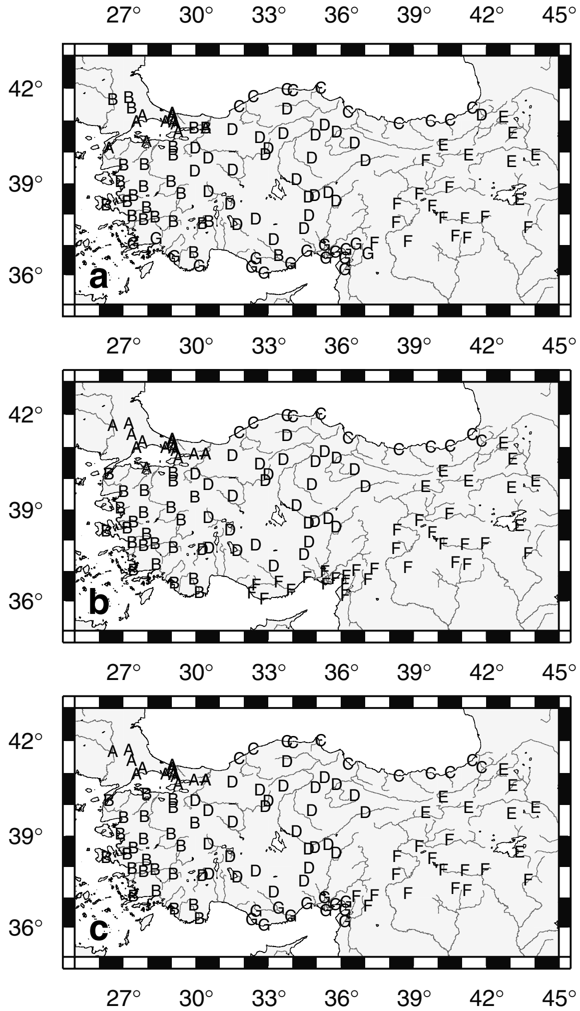

Figure 5. Ward's solutions using (**a**) only mean temperature, (**b**) only total precipitation and (**c**) both three temperature fields and precipitation (see the text for explanation)

Anatolian region combined in a single group in spite of the evident differences. Thus, the seven-class solution was chosen for reasons of practicality (Table III).

It is known that there are seven conventionally accepted climate zones throughout Turkey. In this research, these zones have been questioned using cluster analysis methodology. As a first attempt, we tried to determine climate zones by using the mean temperature field. Figure 5(a) shows the cluster map only using the mean temperature field.

As a second approach, we used only total precipitation data to determine the cluster map. Figure 5(b) indicates the results based on total precipitation only. In contrast to the temperature only clusters the total precipitation cluster experiment gives six different classes similar to the conventional study except for Van (cluster E), the central Anatolian region (cluster D), the Aegean–Marmara region (cluster B), the eastern and southeastern Anatolian region (cluster F), the eastern Mediterranean region (cluster letter E), and the Black Sea region (cluster C). Amazingly, Agri and Erzurum station data are classified with other eastern Anatolian stations.

Since temperature and precipitation are the two primary climatological variables for defining climate zones of a region, we combined a data file consisting of temperature (mean, maximum and minimum) and total

Table III. The seven-cluster solution of Ward's method between clusters algorithm

A	B	C	D	E	F	G
Edirne	Bandırma	Zonguldak	Bolu	Erzincan	Malatya	Anamur
Tekirdağ	Bursa	Inebolu	Kastamonu	Erzurum	Elazıg	Mersin
Kireçburnu	Balıkesir	Sinop	Merzifon	Agrı	Siirt	Adana
Göztepe	Dikili	Samsun	Çorum	Van	Gaziantep	Iskenderun
Kocaeli	Akhisar	Giresun	Sivas	Kars	Sanlıurfa	Dortyol
Lüleburgaz	Manisa	Trabzon	Bilecik	Igdır	Mardin	Antakya
şile	Uşak	Rize	Yozgat	Ardahan	Diyarbakır	Alanya
Florya	Izmir	Artvin	Uşak	Bayburt	Islahiye	Silifke
Kırklareli	Aydın	Hopa	Afyon		Bingöl	Mut
Çorlu	Bodrum	Bozkurt	Kayseri		Adıyaman	Gazipaşa
Kumköy	Mugla	Amasra	Burdur		Hakkari	Yumurtalık
Sakarya	Fethiye		Isparta		Kilis	Karataş
Kartal	Kütahya		Konya		Batman	
Yalova	Çanakkale		Nigde		Ergani	
	Denizli		Eskişehir		Nusaybin	
	Finike		Ankara			
	Edremit		Çankırı			
	Simav		Amasya			
	Ödemiş		Tokat			
	Nazilli		Esenboga			
	Elmalı		Kırşehir			
	Çeşme		Nevşehir			
	Keleş		Kızılcahamam			
	Selçuk		Beyşehir			
			Akşehir			
			Ulukışla			
			Karaman			
			Ürgüp			
			Tomarza			

precipitation data for 113 climate stations. To consider all variables weighted equally in the cluster analysis, we standardized data to zero mean and unit variance. Figure 5(c) shows the results of clusters using the combined meteorological parameters: temperatures and total precipitation. Mainly, there are seven different classes apparent, but these have different boundaries to the regions traditionally used: the northern Marmara region (cluster A), the Aegean and western Mediterranean region (cluster B), the Black Sea region (cluster C), the central Anatolian region (cluster D), the eastern Anatolian region (cluster E), southeastern Anatolian region (cluster F), and the eastern Mediterranean region (cluster G).

6. CONCLUSIONS

In previous studies, the Aegean and Marmara regions were defined as different climatic zones. On the contrary, in this study, these regions have the same characteristic type. Consequently, the Aegean and Marmara regions are thought of as a single climatic zone when temperature and precipitation clustering were performed separately.

All applications of cluster steps could succeed in grouping these stations with others. We think that this could be due to the fact that various high elevations in these areas' stations seem to present different clusters whereas this is not so. All stations in eastern Turkey with elevations over 1400 m form one cluster (E in

Figure 5(c)). None of the other 58 stations has an altitude higher than 1600 m and they are at most 1200 m in altitude.

Also, a similar clustering process is seen in the Black Sea zone. Artvin station behaves differently in this region. Actually, Artvin station is inland and located at a high altitude with respect to the other stations in the Black Sea region. For this reason, it is believed that this station is different from the others. However, although it is inland and has a high altitude, its temperature, and especially its precipitation, properties are similar to all the Black Sea stations. So, it would be more appropriate to add it to the region mentioned. This is considered to be more realistic than the previous condition.

Surprisingly, in all three different experiments, three western Mediterranean stations, Fethiye, Isparta, and Burdur, are classified as in the Aegean–Marmara region. They are not in the eastern Mediterranean region class.

Table IV gives the average values and standard deviations of all four climatological variables according to their classifications for the combined experiment and the conventional regions used.

It is interesting to note that the mean values of all four variables differ from class to class. Therefore, the cluster technique that we used here is quite successful for defining boundaries of the climate regions. Table IV clearly indicates the difference of each classification and presents a solid background for comparison. At a first glance, there are clear differences between temperature and precipitation. For temperatures, the results of our study are more suitable than that of the *'Seven Climate Zones'*. When we consider averages and standard deviations of the minimum temperature $T_{\min}$ for the Black Sea region, these are equal to 5.6 °C and 1.3 °C respectively (Table IV), whereas both of these values are seen to be 2.4 °C and 4.3 °C in the former study (Table IV). Finally, the standard deviation is too high to be compared with standard deviations of the redefined climate zones of Turkey. This is because Kastamonu, Bolu and Merzifon stations are located in the Black Sea region in the former study. Yet, they appear in the central Anatolian region in our study. It is clear that these three stations should be located in the central Anatolian region ($T_{\min} = -2.0\,°C$) instead of the Black Sea region ($T_{min} = 5.6$). In parallel with this, similar examples can be seen in other regions as well, and in different parameters such as maximum and mean temperatures, and the precipitation. It is also evident that standard deviations in temperatures and precipitation are lower than those in a conventional study.

Table IV. Average and standard deviations of meteorological variables of seven climate zones according to (a) the combined experiment and (b) the regions traditionally used

	No. of stations	Average				SD			
		$T_{\min}$ (°C)	$T_{\max}$ (°C)	T_{mean} (°C)	Precip. (mm)	$T_{\min}$ (°C)	$T_{\max}$ (°C)	T_{mean} (°C)	Precip. (mm)
Combined experiment									
A The Marmara region	14	3.8	25.7	13.7	686.2	1.8	1.1	0.6	0.9
B The Aegean–Western Mediterranean region	24	4.0	27.6	15.4	682.0	3.2	2.0	2.5	1.5
C The Black Sea region	11	5.6	25.3	13.7	1175.8	1.3	0.8	0.7	5.5
D The central Anatolian region	29	−2.0	24.4	10.9	429.7	2.2	1.3	1.3	0.8
E The eastern Anatolian region	8	−6.6	19.3	7.2	417.5	3.7	1.3	2.9	0.9
F The southeastern Anatolian region	15	4.2	20.1	15.2	620.6	2.6	2.4	2.4	1.7
G The eastern Mediterranean region	12	9.4	29.0	18.7	797.2	1.5	0.9	0.6	2.2
Conventional acceptance									
1 The Marmara region	19	3.6	26.0	13.8	665.7	1.7	1.2	0.7	1.0
2 The Aegean region	18	3.5	27.4	15.2	662.7	3.6	2.3	2.8	1.6
3 The Black Sea region	19	2.4	25.1	12.4	875.4	4.3	1.7	2.1	5.5
4 The central Anatolian region	17	−2.8	24.2	10.5	404.1	1.9	1.6	1.1	0.8
5 The eastern Anatolian region	11	−3.9	21.4	9.0	490.5	4.9	2.9	3.6	1.9
6 The southeastern Anatolian region	9	5.2	27.9	16.4	610.8	1.7	1.4	1.4	1.4
7 The Mediterranean region	20	7.2	28.1	17.2	730.9	3.8	2.1	2.7	2.2

In summary, we found basically seven main clusters:

1. The Marmara region (A in Figure 5).
2. The Aegean — western Mediterranean region (B in Figure 5).
3. The Black Sea region (C in Figure 5).
4. The central Anatolian region (D in Figure 5).
5. The eastern Anatolian region (E in Figure 5).
6. The southeastern Anatolian region (F in Figure 5).
7. The eastern Mediterranean region (G in Figure 5).

ACKNOWLEDGEMENTS

We wish to show our appreciation to Ercan Kahya and to H. Nüzhet Dalfes for his stimulating discussions and constructive criticisms. We also would like to thank Mehmet Çağlar of the State Meteorological Office for providing data. This work is partially supported by funds provided the ITU Research Activities Secretariat.

REFERENCES

Erinç S. 1984. Climatology and its methods, 3rd edition. Istanbul, Gür-ay Pres Inc. (in Turkish).

Fovell B, Fovell M. 1993. Climate zones of the conterminous United States defined using cluster analysis. *Journal of Climate* **6**: 2103–2135.

Gong X, Richman MB. 1995. On the application of cluster analysis to growing season precipitation data in North America east of the Rockies. *Journal of Climate* **8**: 897–931.

Kalkstein LS, Tan GR, Skindlov JA. 1987. An evaluation of 3 clustering procedures for use in synoptic climatological classification. *Journal of Climate and Applied Meteorology* **26**: 717–730.

Karaca M, Anteplioglu Ü, Karsan H. 1995. Detection of urban heat island in Istanbul, Turkey. *Il Nuovo Cimento C* **18**(1): 49–55.

Karaca M, Deniz A, Tayanç M. 2000. Cyclone track variability over Turkey in association with regional climate. *International Journal of Climatology* **20**: 1225–1236.

Milligan GW. 1980. An examination of the effect of six types of error perturbation on fifteen clustering algorithms. *Psychometrika* **45**: 325–342.

Türkeş M, Sümer U, Kılıç G. 1995. Variations and trends in annual mean air temperatures in Turkey with respect to climatic variability. *International Journal of Climatology* **15**: 557–569.

Türkeş M. 1996. Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology* **16**: 1057–1076.

Türkeş M. 2000. Climate change studies and activities in Turkey. In *Climate Change: Effects on Agriculture in Mediterranean Region*, 25–29 September Zaragoza.

Tayanç M, Dalfes N, Karaca M, Yenigün O. 1998. A comparative assessment of different methods for detecting inhomogeneties in Turkish temperature data set. *International Journal of Climatology* **18**: 561–578.

