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Spatiotemporal variability of precipitation total series over Turkey

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ABSTRACT: Long-term changes and trends in the series of monthly, seasonal and annual precipitation totals of 97 stations in Turkey were analysed by considering their spatial and temporal characteristics. Secular trends in precipitation series were examined with the Mann–Kendall rank correlation test for the general period 1930–2002, whereas spatial variabilities of, and relationships between, the precipitation series at 86 of these stations were investigated by the principal component analysis (PCA) for the period 1953–2002 when the length of data is at its best for the stations subjected to the PCA. Major findings of the paper can be summarized as follows: (1) First principal component (PC1) generally describes climatology of the precipitation totals in Turkey that is closely governed by the large-scale and/or synoptic scale atmospheric features (i.e. surface and upper air pressure and wind systems). (2) In winter, it is very likely that the greater PC1 loadings over the western and south-western parts of Turkey characterized mainly with the Mediterranean rainfall regimes indicate influence of the large-scale atmospheric circulation and associated weather patterns. However, smaller PC1 loadings over the north-eastern and eastern parts of Turkey are very likely related to the influence of the northerly mid-latitude cyclones, and the northerly and easterly circulations linked with the Eastern Europe and the Siberian originated high pressures on spatial variations of winter precipitation. (3) As for the long-term temporal variability, it was detected that there is an apparent decreasing trend in the winter precipitation totals of Turkey, whereas a general increasing trend is dominant in the precipitation totals of spring, summer and autumn seasons. (4) Observed decreasing trends are the strongest over the Mediterranean and the Mediterranean Transition rainfall regime regions. (5) Strong decreasing trends are also mostly found in winter months of the year, while apparent increasing trends show up at some stations in the months of April, August and October. Copyright © 2008 Royal Meteorological Society

KEY WORDS Turkey; Mediterranean climate; precipitation total; observed climate change and variability; spatial relationship; principal component analysis; Mann–Kendall test

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1. Introduction

Recent studies revealed that the climate variability in the 20th century was characterized by apparent precipitation variability at the different time and space scales (e.g. Folland *et al*., 2001; New *et al*., 2001; Trigo *et al*., 2006). During this period of time, particularly after the early 1970s, some marked and long-term changes in precipitation of Turkey occurred in addition to the well-known characteristic seasonal and year-to-year variability. Some of these variations are closely associated with the large-scale modes of circulation variability such as the North Atlantic Oscillation (NAO) (Türkeş and Erlat, 2003, 2005, 2006; Tatli, 2006).

Türkeş (1996, 1998) found for the period 1930–1993 that annual and winter precipitation series of many stations have decreased over a considerable part of Turkey since the early 1970s, and significant long-term decreasing trends showed up mostly over the Mediterranean rainfall region. Summer rainfall series, however, showed a significant increasing trend at some stations, the majority of which were located in the Continental Mediterranean and the Central Anatolia regions of Turkey. Long-term variations in precipitation series, however, were generally characterized by successive dry and wet periods. For annual and winter precipitation series, wet conditions generally occurred during the 1940s, 1960s, late 1970s, early 1980s and mid- to late 1990s, whereas dry conditions generally dominated over early to mid-1930s, early to mid-1970s, mid to late 1980s, early 1990s and 1999/2000 over most of Turkey (Türkeş, 1998, 2003). Türkeş (1999), based on the annual aridity index series of Turkey, also pointed out that there was a general tendency from the humid conditions around the 1960s towards dry sub-humid climatic conditions at many Turkish stations. In contrast, aridity index values tended to increase significantly towards humid or semi-humid climatic conditions over the northern part of the Continental Central Anatolia region of Turkey. Türkeş *et al*. (2002a) investigated persistence and periodicity components in annual and seasonal precipitation anomaly series at 91 stations of Turkey. Tatli *et al*. (2004) applied a new downscaling method for regional climate process. Their results show

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that precipitation regimes of the coastal regions of Turkey are mainly controlled by the large-scale pressure systems and upper atmospheric circulation.

On the other hand, recent studies dealing with influences arising from year-to-year and long-period variability of some atmospheric oscillation indices such as the NAO and the North Sea – Caspian Pattern (NCP) on precipitation changes and variability of Turkey (e.g. Kutiel *et al*., 2002; Türkeş and Erlat, 2003, 2005, 2006; Kutiel and Türkeş, 2005; Tatli, 2006) have revealed the considerable spatial and temporal changes in the precipitation total series of Turkey during the last 10 years.

One of the main purposes determined for this study is to re-evaluate the long-term trends and variations in Turkish precipitation series both for seasonal and monthly time scales. In addition to temporal variability (i.e. long-term trends) of precipitation, its spatial variability that can be affected from a set of possible local and regional factors is also important for large countries with different climate regimes such as Turkey. This requires studying the spatial variability and relationships among the precipitation total series of stations by using objective methods such as the principal component analysis (PCA). Therefore, this study has not only re-evaluated long-term variations and trends in monthly, seasonal and annual series of the precipitation totals over Turkey, but it has also aimed at a new analysis of the series of precipitation totals by the PCA in order to show the spatial relationships (geographical autocorrelations) among the stations that are randomly distributed over the country. Evaluation of the PCA results was performed by considering the regional-scale physical geographic controls on the major hydro-climatological peculiarities of the country, most of which is a large peninsula and is characterized with apparently high and complex topography indicating considerable continentality towards inner and eastern regions. Finally, the main purpose of the paper is:

(1) to apply the PCA based on covariance matrix to the seasonally scaled precipitation total series of 86 stations in Turkey, with an equal length of observations for the period 1953–2002, in order to determine principal spatial modes of variability in these series and/or to reveal homogeneous geographical autocorrelation regions of the precipitation variability;
(2) to analyse not only seasonal and annual but also monthly precipitation total series of 97 stations to reveal their long-term trends and variations; and
(3) to explain trend features (i.e. nature and magnitude of the observed trends).

2. Background of the Mediterranean precipitation variability

There have been plenty of studies dealing with the year-to-year and long-term precipitation variations over the Mediterranean region. Giorgi (2002) found negative (positive) winter precipitation trends over the eastern (western) Mediterranean land area for the 20th century. Spring and autumn precipitation totals present a different picture, with negative trends concentrated over Iberia and central Mediterranean regions (Schönwise *et al*., 1994). This is supported by more regionalized studies, such as the one by González-Rouco *et al*. (2001) for the Iberian Peninsula, showing a positive seasonal trend for this time interval in winter and negative trends in spring and autumn. In Italy, a significant negative trend observed in annual precipitation totals is mainly due to the spring season (Brunetti *et al*., 2006). Using the same data as Jacobeit (2000), Giorgi (2002) showed for the last three decades some rainfall increases in autumn (western Iberia and southern Turkey), but dominating decreases in winter and spring. For the period 1951–2000, opposite to the prevailing decreasing trend, there is some increase in winter precipitation from southern Israel to northern Libya in accordance with increased positive modes of the Mediterranean Oscillation (Jacobeit *et al*., 2004). Norrant and Douguédroit (2006) indicated that the prevailing trends for the second half of the 20th century over the Mediterranean are negative in winter and spring, although areas with significant trends are relatively restricted, depending on the month. Norrant and Douguédroit (2006) also revealed that precipitation trends appear to significantly diminish primarily during winter months, March in the Atlantic region, October in the Mediterranean Spain, December in the Lions and Genoa Gulfs, January, winter and annually in Greece, winter and annually in Italy and winter in the Near East, and increase in April in the two gulfs.

Time-series evaluations of regional series indicate that winter precipitation totals have been decreasing in many regions that are not statistically significant in view of the large variability (Xoplaki, 2002; Norrant and Douguédroit, 2006). For the Mediterranean Sea, precipitation variability and water budget have been investigated by using gauge-satellite merged products and atmospheric re-analyses (Mariotti *et al*., 2002). Mariotti *et al*. (2002) showed that during the last 50 years of the 20th century, average winter precipitation of the Mediterranean decreased by about 20%, with the decrease mostly occurring during the late 1970s to early 1990s. This implies a similar increase in the Mediterranean atmospheric water deficit with potentially important impacts on the Mediterranean Sea circulation (Trigo *et al*., 2006). Xoplaki *et al*. (2004) showed monthly time evolution of the spatially averaged precipitation anomalies both for the instrumental data of about 300 stations and the NCEP/NCAR re-analysis data. They also found that decadal changes showed a good agreement between both datasets in depicting relatively wet and dry periods: relative maxima took place in the early 1950s, 1960s, and late 1970s to early 1980s and late 1990s, while relative minima occurred in the late 1950s, early 1970s and early 1990s.

In addition to trends, as Türkeş (1996, 1998, 2003); Türkeş and Erlat (2005) and Xoplaki *et al*. (2004) revealed, the precipitation variations over the Mediterranean region and Turkey are mostly characterized by

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runs of dry and wet (rainy) periods: generally wet periods are weak, short and infrequent, while dry periods are strong, long and frequent. A glance at the Mediterranean regional winter precipitation trends reveals a more detailed picture of the general findings. Some examples of the regional studies dealing with precipitation changes and trends of the Mediterranean region are as follows: Kutiel *et al*. (1996); Brunetti *et al*. (2001); Ramos (2001); Brunet *et al*. (2007); Feidas *et al*. (2007); and for Turkey, Türkeş (1996, 1998, 1999, 2003); Kutiel *et al*. (2001); Türkeş *et al*. (2002a, 2007); Türkeş and Erlat (2003, 2005); Tatlı *et al*. (2004); Koç and İrdem (2005); Türkeş and Sariş (2007).

3. Data and methodology

3.1. Data

We used daily precipitation totals recorded at 97 stations of Turkish State Meteorological Service (TSMS). The average record length of the stations was 64 years for the study period 1930–2002. We arranged these series as climatological seasons: winter consists of December, January and February; and March, April and May are considered as spring; similarly June, July and August are grouped as summer; and September, October and November are autumn. Spatial assessments of the climatological and statistical analyses were made based on the seven rainfall regime regions of Turkey, which were originally developed by Türkeş (1996, 1998), considering the seasonal variability of precipitation and physical geographic characteristics of Turkey (Figure 1).

3.2. Application of the Kruskal–Wallis test to homogeneity assessment

For determining whether the time-series are homogeneous or not, the non-parametric *Kruskal–Wallis* $(K-W)$ test was used (Sneyers, 1990). For calculating the K–W test statistic (X_K), observations of each sub-period (or each series) are first replaced by their ranks r_{ij} as occupied in the total ordered sample series. If k is the number of sub-periods (or independent series); n_j, $j = 1, 2, \ldots, k$ is the sample size of the sub-periods j, then test statistic (X_K) is written as

$$X_K = \left[\frac{12}{n(n+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} \right] - 3(n+1) \tag{1}$$

where

$$R_j = \sum_{i=1}^{n_j} r_{ij} \tag{2}$$

and

$$n = \sum_{j=1}^{k} n_j \tag{3}$$

Under the null hypothesis of the homogeneity of the means, the statistic X_K is distributed approximately as χ^2 with $(k-1)$ degrees of freedom. We also verified the homogeneity of variances by using the same test. The homogeneity of variances is realized by applying the same test to the series obtained, but by replacing each rank r_{ij} with the absolute value to the deviation from the general average (Sneyers, 1990). Sample size

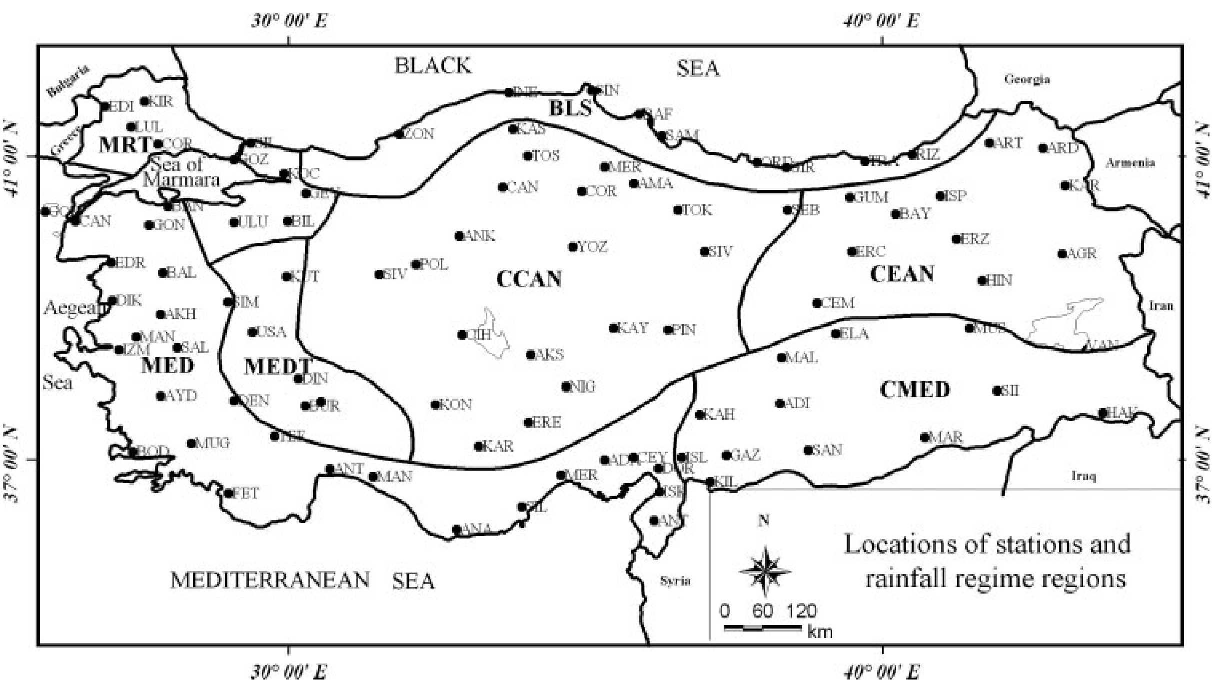

Figure 1. The locations of stations and rainfall regime regions over Turkey. BLS, Black Sea; MRT, Marmara Transition; MED, Mediterranean; MEDT, Mediterranean Transition; CMED, Continental Mediterranean; CCAN, Continental Central Anatolia; and CEAN, Continental Eastern Anatolia.

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of sub-periods and the significance level of the test were taken as $n_j = 5$ and the $\alpha = 0.05$, respectively. Then, we made a subjective assessment for each statistically significant result with the help of additional information available with plotted time-series graphs and a station history file prepared by Türkeş (1996, 1998) based on the official documents of TSMS. For the present study, inhomogeneity indicates non-climatic strong jumps or step-wise changes in the mean of the series. According to the results of the K–W homogeneity test, we determined some statistical inhomogeneities in winter and autumn precipitation series. However, only a few stations have abrupt changes in the series; thus most of the statistical inhomogeneities are very likely related to the long-period fluctuations and significant trends, both of which are accepted within other non-randomness characteristics of the series of climatological observations (WMO, 1966; Sneyers, 1990, 1992; Türkeş, 1996, 1999; Türkeş *et al.*, 2002a,b, etc.).

3.3. Principal component analysis

We applied PCA [traditionally known as Empirical Orthogonal Functions (EOFs) in studies of the atmospheric sciences] to the seasonal precipitation total series of 86 stations in Turkey. These stations have series with an equal length of record for the period 1953–2002. PCA and the closely related principal factor analysis (PFA) of multivariate techniques have been widely used in meteorology and climatology (Preisendorfer, 1988; Wilks, 1995). The major features of PCA are briefly explained here.

According to Tatli *et al.* (2004, 2005), all matrices are organized such that the rows represent simultaneous observations and columns indicate observed variables at different sites. Without going into details, assume the first- and second-order statistics of a multivariate **X** (observation matrix) is known or can be estimated from the sample. In PC transform, the matrix of the variables (**X**) is centred by subtracting its mean, and then the covariance matrix of **X** is obtained as follows:

$$\mathbf{S_{XX}} = E(\mathbf{X^T X}) \tag{4}$$

where E represents expectation operator. We have to keep in mind here that the principal components (PCs) are not invariant under scaling. Without loss of generality, an orthogonal decomposition of $\mathbf{S_{XX}}$ is also given as follows:

$$\mathbf{S_{XX}} = \mathbf{U_X D_X U_X^T} \tag{5}$$

where $\mathbf{U}_X$ is the matrix that contains the orthonormal eigenvectors of $\mathbf{S_{XX}}$ and $\mathbf{D_x} = \mathrm{diag}(\lambda_1, \ldots.., \lambda_k)$ is the diagonal matrix of the eigenvalues of $\mathbf{S_{XX}}$ in a decreasing magnitude order (Preisendorfer, 1988; Tatli *et al.*, 2004, 2005). The PCs are then computed by

$$\mathbf{V_X} = \mathbf{XU_X} \tag{6}$$

where each of the columns of $\mathbf{V_X}$ illustrates the individual PC and inversely, the reconstruction of **X** is obtained as:

$$\mathbf{X} = \mathbf{V_X U_X^T} \tag{7}$$

The PCA technique discussed above is a distribution-free method with no underlying statistical model, but in the case of PFA, the multivariate **X** is traditionally reconstructed as in the following:

$$\mathbf{X} = \mathbf{F_X A_X} + \mathbf{G_X} \tag{8}$$

where $\mathbf{F_X}$ and $\mathbf{G_X}$ are called common factors (CFs or latent variables) and white noise components (or specific components), respectively. The matrix $\mathbf{A_X}$ consists of the factor loadings defined as

$$\mathbf{S_{XX}} = \mathbf{A_X A^T{}_X} = \mathbf{U_X D^{1/2} D^{1/2} U_X^T} \tag{9}$$

There are no statistical constraints on PCs, but CFs must be the Gaussian in a PFA model (Reyment and Jöreskog, 1993). The CFs could be rotated (Richman, 1985), for example, by the varimax method (Kaiser, 1959) for simplifying evaluation of the PC patterns easily.

The signs of the PC patterns have no meaning to interpret them as in the traditional linear-correlation analysis; they just show different systems might affect the stations over the related regions. On the other hand, PCA is a black-box computation method that the signs or scaling of them brings no physical description of the local-climate systems (details may be found in Preisendorfer, 1988; Wilks, 1995; Tatli *et al.*, 2004, 2005; Brunet *et al.*, 2007).

3.4. Trend analysis

We have detected the long-term trends in precipitation total series by using the non-parametric *Mann–Kendall (M–K) rank correlation test* (WMO, 1966). The *M–K* rank correlation test has some significant advantages over the parametric trend techniques, because the *M–K* technique is distribution-free (i.e. independent from the form of a known frequency distribution) over the series of observations, and it is also non-linear in nature.

Before applying the *M–K* test, the original observations of x_i are replaced by their corresponding ranks k_i, such that each term is assigned a number ranging from 1 to N reflecting its magnitude relative to the magnitudes of all other terms. Then, for each element, k_i, the number n_i of elements k_j preceding it $(i > j)$ is calculated with $(k_i > k_j)$: The value of the first term of the series k_1 is compared with the values of all latter terms in the series from *2nd* to *Nth*; number of the latter terms whose values exceed k_1 is counted up, and then this number is denoted as n_1. Then, value of the *2nd* term k_2 is compared with the values of all the latter terms; number of latter terms that exceed k_2 is counted and it is denoted as n_2. This procedure is continued for each term of the series to k_{N-1} and its corresponding number n_{N-1}

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for each station's precipitation data. P statistic is then obtained by,

$$P = \sum_{i=1}^{N-1} n_i \tag{10}$$

M–K rank correlation statistic τ is derived from N and P by the following equation:

$$\tau = \frac{4P}{N(N-1)} - 1 \tag{11}$$

Distribution function of τ is the Gaussian (normal) for all N larger than about 10, with an expected value of zero and variance (τ_{var}) equal to

$$\tau_{\mathrm{var}} = \frac{(4N+10)}{9N(n-1)} \tag{12}$$

and the significance test $(\tau)_{\mathrm{t}}$ is then calculated with

$$(\tau)_{\mathrm{t}} = 0 \mp t_g\sqrt{\tau_{\mathrm{var}}} \tag{13}$$

where t_g is the desired probability point of the normal distribution with a two-sided test, which is equal to 1.960 and 2.58 for the 5 and 1% levels of significance, respectively. The null hypothesis for the absence of any trend in the series is rejected for the large values of $|\tau_{\mathrm{t}}|$ for the desired level of significance.

4. Results of analysis

4.1. Principal components of precipitation totals

Even though we obtained the entire PCs of the seasonal precipitation series, we have given here the results of the first six PCs (Table I) which are significant according to the method of *scree-plot* (Wilks, 1995) (figures not given here) for the eigenvalues of the 86 stations. These six PCs explain 78, 68, 65 and 70% of the cumulative variances of winter, spring, summer and autumn series, respectively (Table I). However, we have interpreted here only the first three PCs, and prepared the geographical distribution maps of the principal factor loadings by drawing contours (Figures 2, 3, 4 and 5). Considering the first three PCs is sufficient for a PC pattern based analysis, since the first few PCs are generally associated with the large- or synoptic-scale climatic patterns over Turkey, while the rest of the PCs are mostly related to the local information content (Tatli *et al.*, 2005). On the other hand, maps of the precipitation climatology of Turkey such as spatial variations of the long-term precipitation averages, coefficients of variation and seasonality of the precipitation totals, etc. were not given in this paper, because the detailed climatological assessments for seasonal and annual precipitation totals had been performed previously by Türkeş (1996, 1998, 2003); Kadıoğlu (2000) and Tatlı *et al.* (2004). Results from the PCA are summarized as follows.

Table I. Eigenvalues, percentage explained variance and percentage of cumulative variance of the non-rotated first six principal components (PCs) for the seasonal precipitation totals of Turkey.

PC	Eigenvalue	Explained variance (%)	Cumulative variance (%)
		Winter	
1	387385.31	46.55	46.55
2	113101.14	13.59	60.14
3	51683.71	6.21	66.35
4	43220.05	5.19	71.54
5	34744.02	4.17	75.71
6	20910.88	2.51	78.23
		Spring	
1	113810.12	32.59	32.59
2	47445.80	13.58	46.17
3	25830.41	7.40	53.57
4	20630.30	5.91	59.47
5	16452.53	4.71	64.19
6	13864.45	3.97	68.15
		Summer	
1	43543.06	27.27	27.27
2	17982.68	11.26	38.53
3	15136.24	9.48	48.01
4	11072.82	6.93	54.94
5	8409.70	5.26	60.20
6	7610.15	4.76	64.97
		Autumn	
1	121395.37	28.80	28.80
2	62152.88	14.74	43.54
3	47952.76	11.38	54.92
4	29946.15	7.10	62.02
5	18815.83	4.46	66.48
6	15414.34	3.66	70.14

4.1.1. Winter PCs

According to the PCA that was applied to the winter precipitation total series of 86 stations, eigenvalue of the first PC explains the variance in the temporal variability of winter precipitation series with a high rate of 46.5% (Table I). The highest PCs with negative signs are found in the map of the PC1 (Figure 2(a)). The magnitude of correlation coefficients displays an evident decreasing distribution pattern from western regions of the country to the east. Most strong patterns have fallen out in the Mediterranean (MED), Mediterranean Transition (MEDT) and western Continental Central Anatolia (CCAN) rainfall regime regions in winter. Because a considerable amount of Turkey's precipitation falls in winter (Türkeş, 1998), the observed patterns of winter precipitation are significant and spatially coherent over a large area (Figure 2(a)). Greater PC1 loadings over the western and south-western parts of Turkey, precipitation regimes of which are mainly characterized with the macro Mediterranean climate and the Mediterranean transition to the

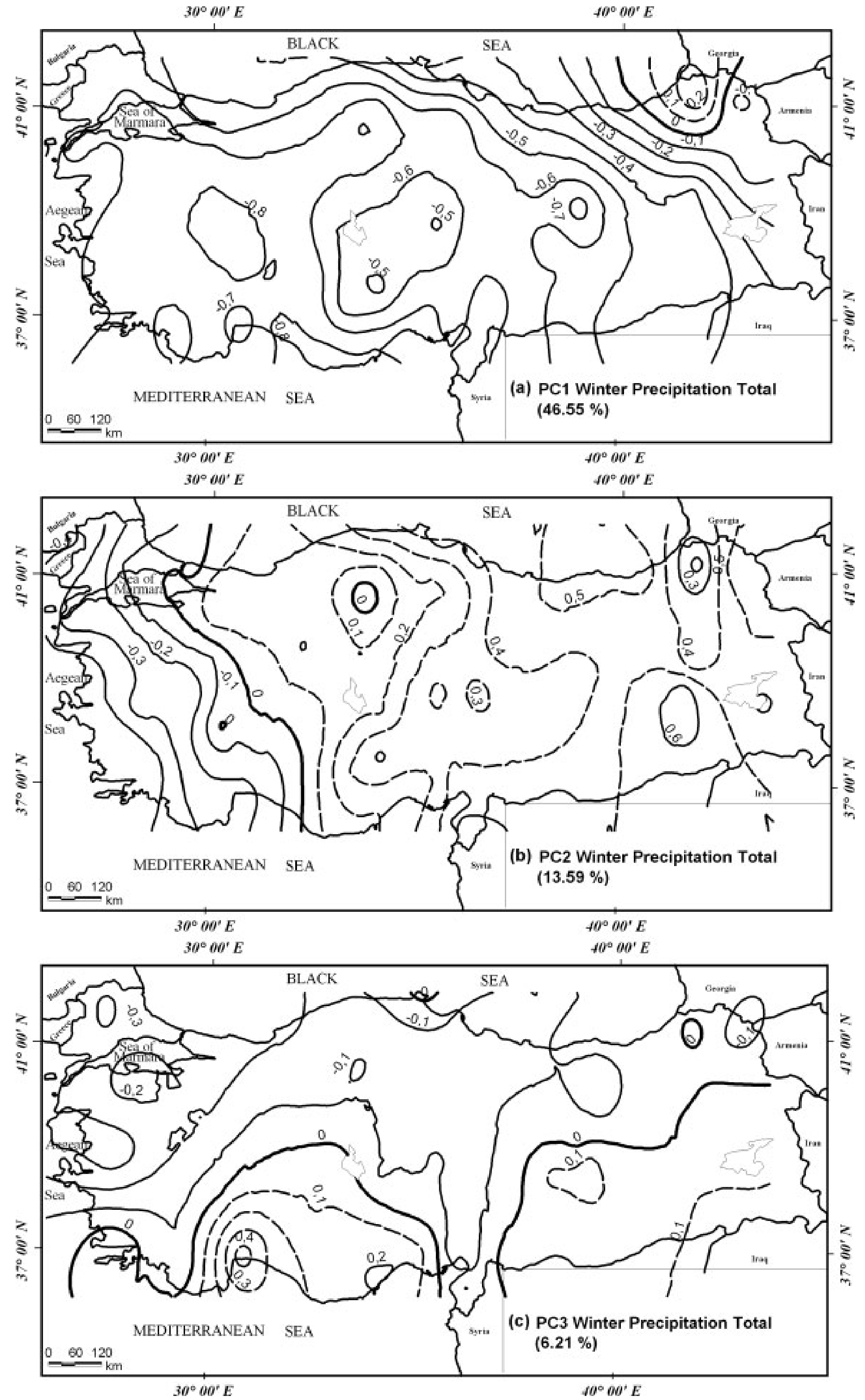

Figure 2. Geographical distribution patterns for loadings of the first three principal components (PCs) computed for winter precipitation total series of 86 stations in Turkey. This map displays the correlation patterns between the seasonal precipitation total series and the PCs. In the PC maps, solid and solid-bold contours display the negative loadings and zero values respectively, whereas the dashed lines show positive loadings.

continental Anatolia, indicate influence of the large-scale atmospheric circulation and associated weather system patterns. This influence is mainly arising from particularly the northeast Atlantic and Mediterranean originated large-scale frontal cyclones along with the Azores high. However, smaller loadings from the PC1 over the northeastern and eastern parts of Turkey are related to the influence of the more northerly mid-latitude cyclones and

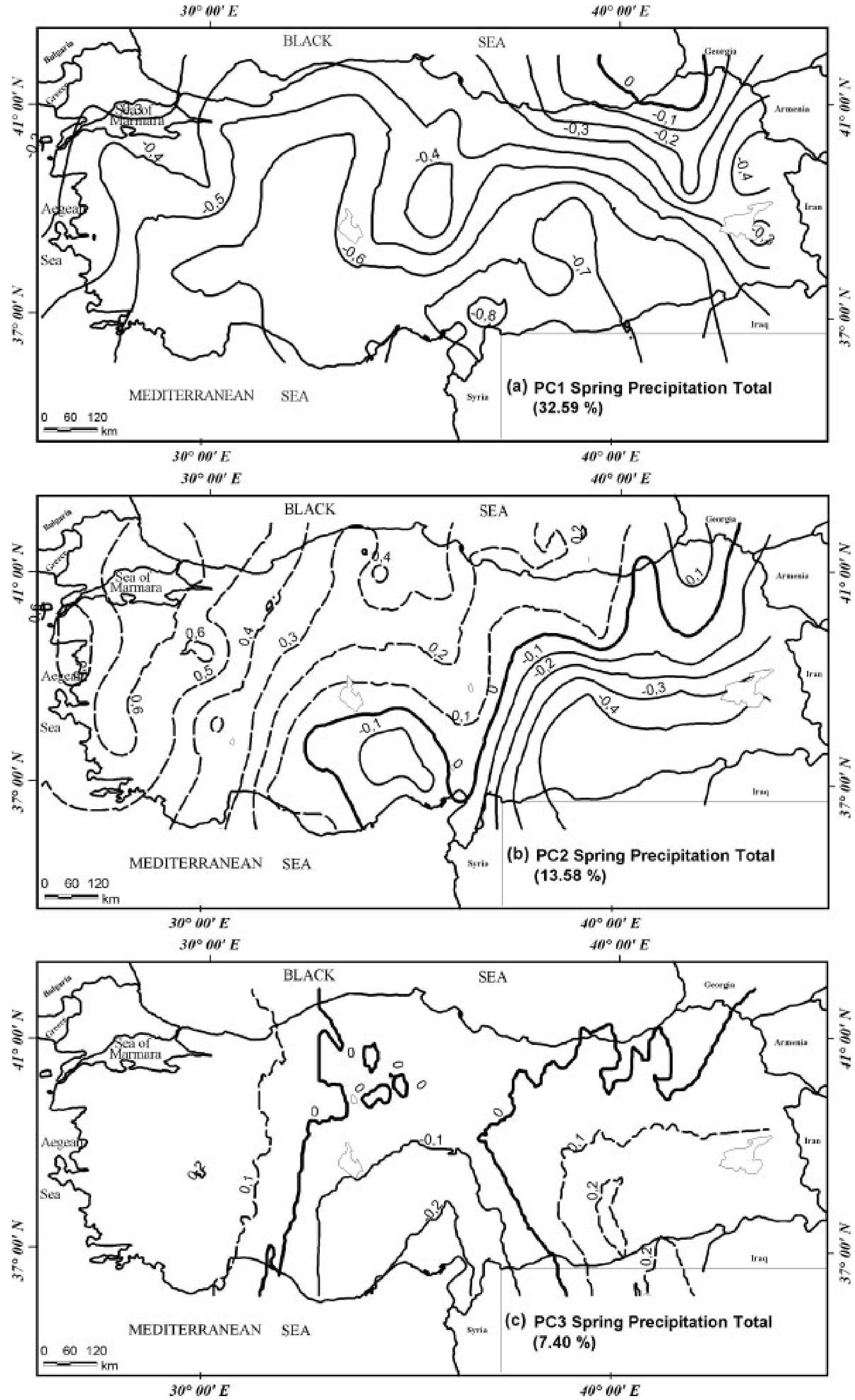

Figure 3. As in Figure 2, but for the PCs of spring precipitation totals.

the northerly and easterly circulations linked with the Eastern Europe and the Siberian originated high pressures on precipitation variations over these regions.

The eigenvalue of the second principal component (PC2) explains the 13.6% of the variance in the winter precipitation totals (Table I). The map of the PC2 for the precipitation totals indicates evident spatial relationships among the stations that are characterized with negative values over west of Turkey and positive values in the east. On the other hand, in contrast to the PC1, the highest loadings are found in the east, over the regions of the CMED and Continental Eastern Anatolia

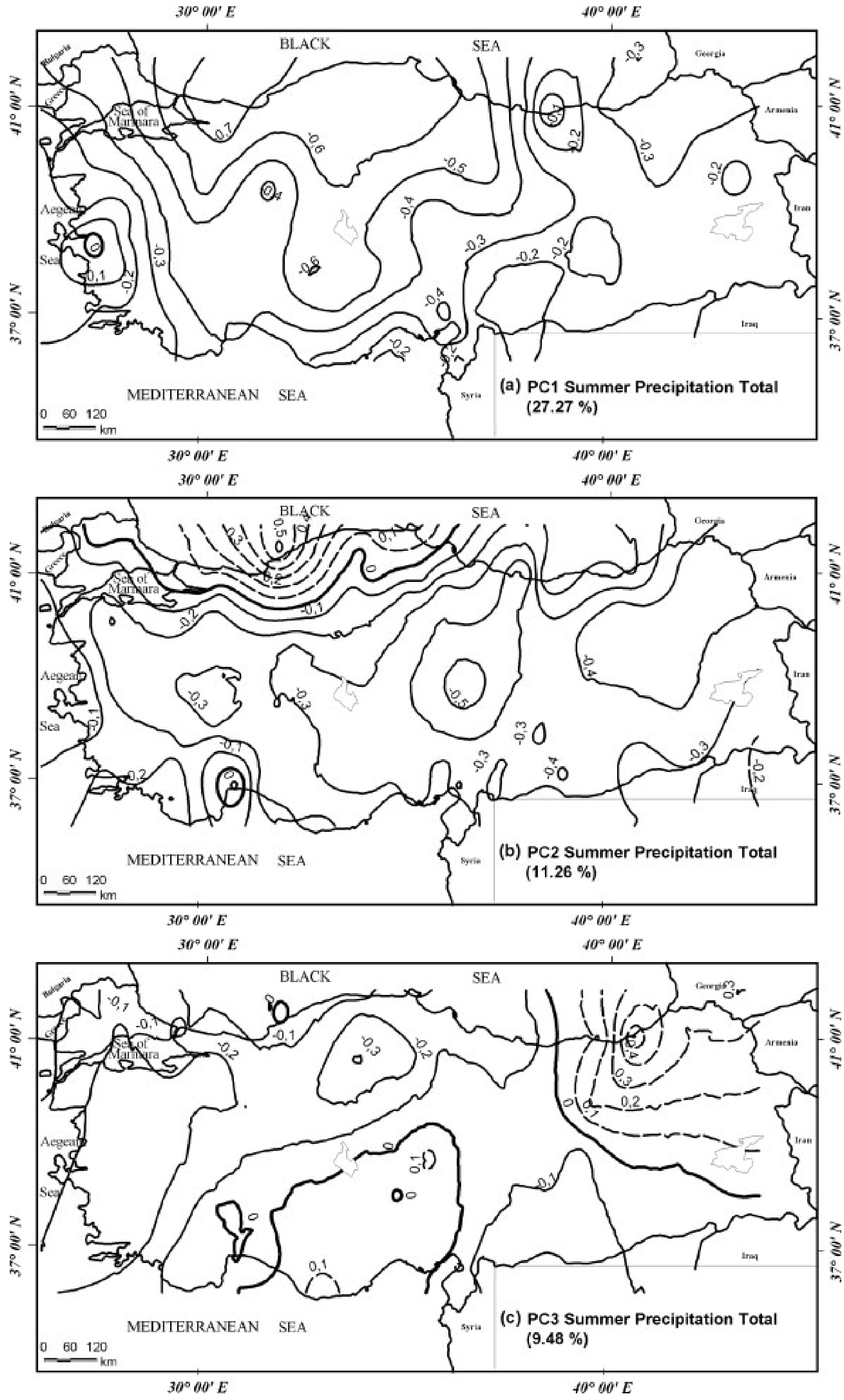

Figure 4. As in Figure 2, but for the PCs of summer precipitation totals.

(CEAN) (Figure 2(b)). The pattern of the PC2 not only explains the influences of the humid–warm and thus conditionally unstable Mediterranean weather systems coming directly from the west on geographical autocorrelations of winter precipitation totals over these regions, but also depicts the influences arising from increasing continentality from west towards the high mountainous Eastern Anatolia.

The map of the third principal component (PC3), which explains only 6.2% of the variance in the winter precipitation totals, does not prove the existence of any significant and apparent geographical autocorrelation pattern, with

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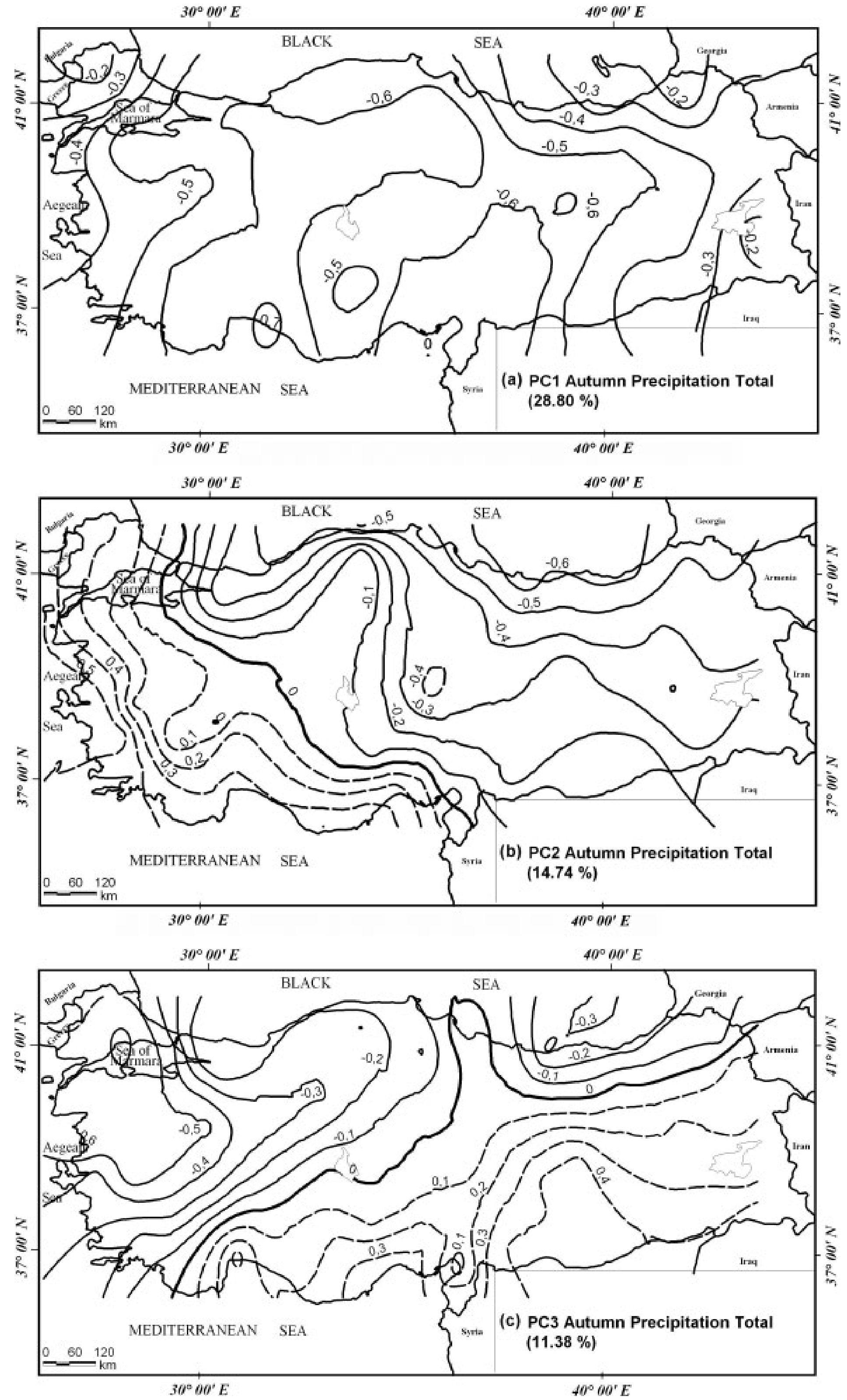

Figure 5. As in Figure 2, but for the PCs of autumn precipitation totals.

the exception of the spatial relationship patterns with the relatively strong negative signs in the northernmost part of the Mediterranean rainfall region (i.e. Aegean portion of the MED) and with the relatively strong positive signs in the Antalya district of the western sub-region of the MED region (Figure 2(c)). The PC3 pattern of the winter precipitation totals of Turkey explains the probable marine-temperate influences of the Mediterranean Sea on the winter precipitation totals making stronger direct influence of the mid-latitude cyclones over the region.

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4.1.2. Spring PCs

The first eigenvalue of the PCA applied to the spring precipitation totals describes 32.6% of the variance in the spring precipitation variability of Turkey (Table I). The loading pattern of the PC1 over the north-eastern portion of Turkey including the coastal belt of the eastern Black Sea along with the continental and high north-eastern Anatolia sub-region, explains the local effects on spring precipitation totals. Influence of local effects varies from the coastal belt to the continental interiors with respect to humidity (maritime effect), orography, altitude and continentality. The spatially coherent significant PC1 pattern with a maximum centre in the eastern Mediterranean sub-region (i.e. Adana-Ýskenderun district) is characterized by negative-sign high correlations found in the rainfall regions of CMED, CCAN, MED and partly Marmara Transition (MRT) (Figure 3(a)). Consequently, with the exception of loadings in the eastern Black Sea and north-eastern Anatolia sub-regions, PC1, which is spatially coherent over most of Turkey, clearly reveals influences and spatial controls of rainfall forming deep and active frontal cyclones on the variations of the spring precipitation totals.

The eigenvalue of PC2 explains about 13.6% of the variance in the spring precipitation totals of Turkey (Table I). It is clearly seen that the loadings of PC2 calculated for the spring precipitation exhibit two-mode spatial relationships over Turkey. Spring precipitation variability in the west and northwest portions of Turkey is characterized by spatially coherent and significant positive values, whereas basically the CMED region and a partly southern part of the CEAN region are completely represented by the negative loadings (Figure 3(b)). The CCAN region and the eastern MED sub-region are also the transition areas. Therefore, the loadings with great positive sign explain the influences of maritime air masses and mid-latitude cyclones on the spatial relations and variability of spring precipitation over western Turkey, whereas the significant negative values explain the geographical autocorrelation of the spring precipitation totals controlled mainly by regional convective instability showers and thunderstorms, particularly in the CMED rainfall region.

However, according to the pattern of the loadings of PC3 which has an eigenvalue explaining only about 7.4% of the variance for the spring precipitation totals, it does not show any apparent and significant correlation pattern (Table I; Figure 3(c)).

4.1.3. Summer PCs

The eigenvalue of PC1 computed for the summer precipitation total series of Turkey carries the information related to 27.3% of the year-to-year variability in summer precipitation (Table I). There are no significant patterns at the east and northeast of the map plotted for the PC1, whereas the large area extending from west of the Black Sea(BLS) region via the CCAN region to the Aegean and Mediterranean coasts are dominated by negative-sign loadings underlining significant relationships with respect to the spatial variability of spring precipitation totals of the stations (Figure 4(a)). This pattern very likely occurred in the course of the direct influence of the mid-latitude cyclones associated with the large-scale atmospheric circulations reaching from Eastern Europe to Turkey in summer.

The eigenvalue of PC2 explains about 11.3% of the variance in the summer precipitation totals in Turkey (Table I). It is seen clearly from the distribution map of PC2 that, because the direction of the coast is generally suitable against northerly circulations, a positive centre of PC is located over the western Black Sea sub-region (Figure 4(b)). This well explains orographic rainfalls over the region formed by the north-westerly air flows carrying the Atlantic sourced humid and cold air masses (maritime polar) to the north of Turkey. On the other hand, negative-sign significant spatial relationships dominated over all continental type rainfall regions of Turkey along with the Eastern Mediterranean sub-region and the CMED region (Figure 4(b)), explaining the effects of the showers and thunderstorms with intensive rainfalls related to the regional and/or local convective instability conditions in summer.

PC3, which explains about 9.5% of the variance in the summer precipitation variability, indicates significant geographical autocorrelations over the rainiest districts of Turkey, the eastern Black Sea and the north-eastern Anatolia sub-regions (Türkeş, 1998) (Table I, Figure 4(c)). The PC3 loadings over these areas well explain coastal orographic and interior-continental local convection rainfalls (rain showers and ordinary air mass and/or multi-cell thunderstorms), both of which have been closely related to, and controlled by, the northerly sector surface and upper air flows and atmospheric disturbances such as upper air troughs, centres of lows etc. Regional surface warming of the Eastern Anatolia Mountains and the high north-eastern Anatolia plateau contributes to and strengthens this mechanism in the summer season.

4.1.4. Autumn PCs

The eigenvalue of PC1 computed for the autumn precipitation total series of Turkey is at the level that explains only 28.8% of the variance in the autumn series (Table I). Negative-sign significant relationships found over the large area from western and mid-BLS sub-regions characterized by higher autumn precipitation amounts to the western Mediterranean sub-region of Turkey (Figure 5(a)), explain influences of the mid-latitude and the Mediterranean cyclones even though they are not as effective as in the winter season (Türkeş, 1998; Türkeş and Erlat, 2003). Negative-sign decreasing correlation pattern at the west indicates influence of the Azores high pressure that has not lost its seasonal activity yet, whereas the relationship pattern at the east indicates influences of both topography and continentality in addition to the lack of rain bringing mid-latitude systems in this season (Türkeş, 1998; Türkeş and Erlat, 2003).

The eigenvalue of PC2 for the autumn precipitation totals is related to about 14.7% of the variance in the series of autumn precipitation totals in Turkey (Table I). Spatial variability of the PC2 loadings exhibits a two-pole pattern: one is the negatively correlated distribution pattern over the BLS rainfall regime region with a significant value of −0.6 in the eastern Black Sea coast; and the second is the positively correlated distribution pattern with a maximum of 0.5 at the west, mainly on the Aegean coast of the country (Figure 5(b)). Loadings of PC2 clearly indicate the influence of the northerly circulation and orography over the BLS rainfall region and the influence of the topography (altitude, high mountains and plateaus) and continentality on the occurrence and spatial variability of autumn precipitation over the mountainous CEAN rainfall region. On the other hand, positive PC2 loadings at the west and south of the country mainly explain the influence of the frontal Mediterranean cyclones on the autumn precipitation coming directly through the Mediterranean basin to Turkey.

Loadings of PC3 explain three main spatial correlation patterns over Turkey. The strongest and most apparent one of these patterns shows spatially coherent correlation over west and north-west Turkey including the MRT region and the Aegean part of the MED region (Figure 5(c)). This spatial correlation pattern shows that the mid-latitude and the Mediterranean depressions associated with the large-scale atmospheric circulations, which have direct influence on the autumn precipitation occurrence in this season start to be active beginning from the north-west of the country. On the other hand, positive-sign loadings from the autumn PC3 being evident on the Mediterranean coast of Turkey and over the CMED region explain the ongoing influence of the Monsoon low (i.e. circulation-based effect of the Asiatic summer monsoon low), whereas the loadings in the CEAN region are very likely related to the orographic and convectional rainfalls over the high plateaus and mountainous areas of the region caused by northerly upper-air flows.

4.2. Trends and changes in precipitation totals

4.2.1. Results for seasonal and annual series

In winter, low-frequency fluctuations and strong decreasing trends are obtained in the precipitation totals of the

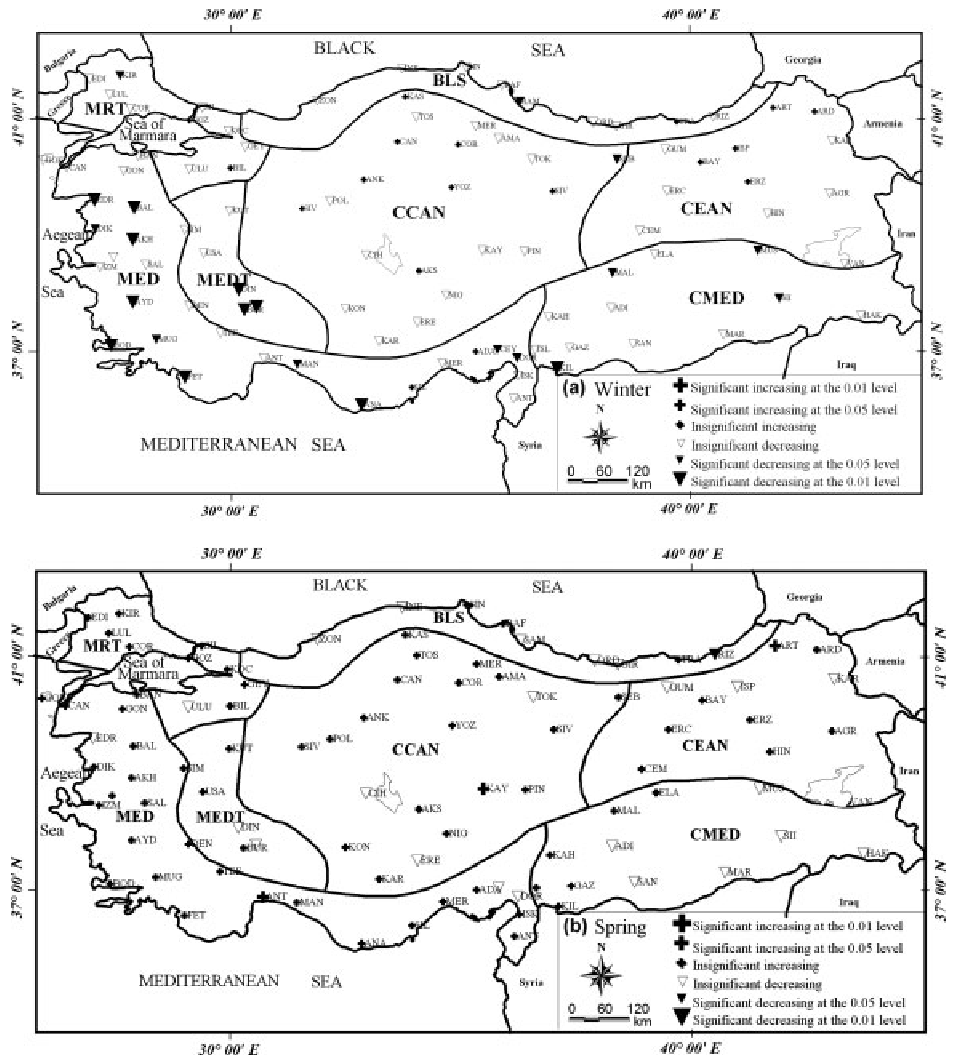

Figure 6. Geographical distribution of the long-term trends of winter (a) and spring (b) precipitation total series at 97 stations of Turkey according to the Mann–Kendall rank correlation test.

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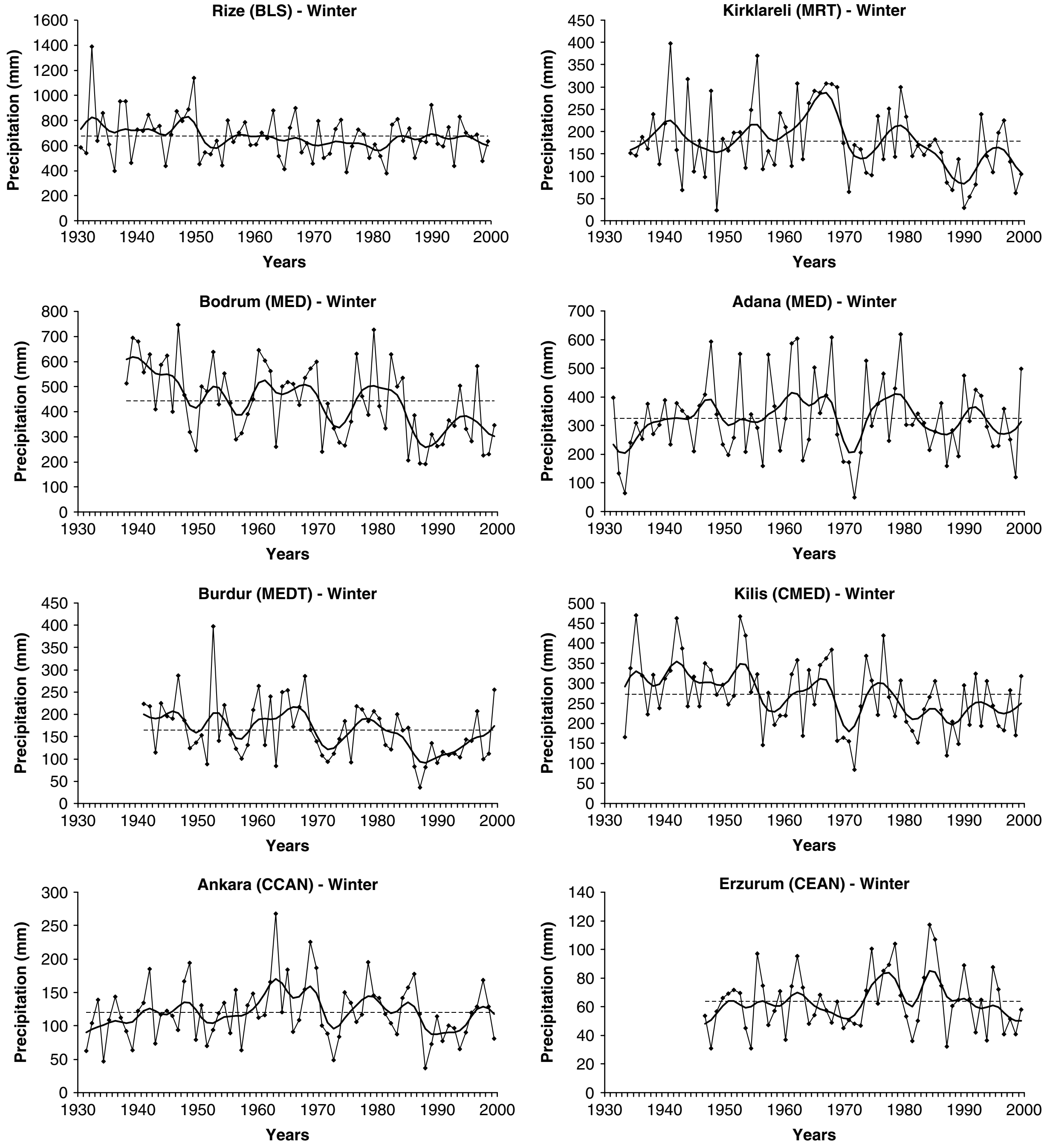

Figure 7. Long-term variations (– ◆ –) in winter precipitation total series at selected representative stations of Turkey's rainfall regime regions. Year-to-year variations in the series are smoothed with five-point Gaussian Filter (———), and (- - - -) displays long-term average of the precipitation total series.

stations characterized mainly by the Mediterranean type rainfall regimes. According to the resultant test statistics $(\tau)_t$ obtained from the $M-K$ rank correlation test, apparent decreasing trends in precipitation series are found to be statistically significant at the 5% level at 22 stations. The MED and the MEDT rainfall regions have the strongest decreased precipitation totals, 12 and 3 stations of which are characterized by statistically significant decreasing trends, respectively, while the CCAN, BLS and CEAN rainfall regions are generally random against any significant trend (Figure 6(a)).

Figures 7, 8, 10 and 11 display the long-term variations in seasonal (except summer) and annual precipitation series at selected stations, respectively. These stations are selected because they are representative of the dominant trend characteristics of the rainfall regime regions in that season. A long-term decreasing trend prevails in series of all regions in winter. However, recent years of winter series have been generally characterized by opposite changes towards somewhat increased precipitation (Figure 7), due to low-frequency fluctuations that are dominant long-term temporal characteristics of the

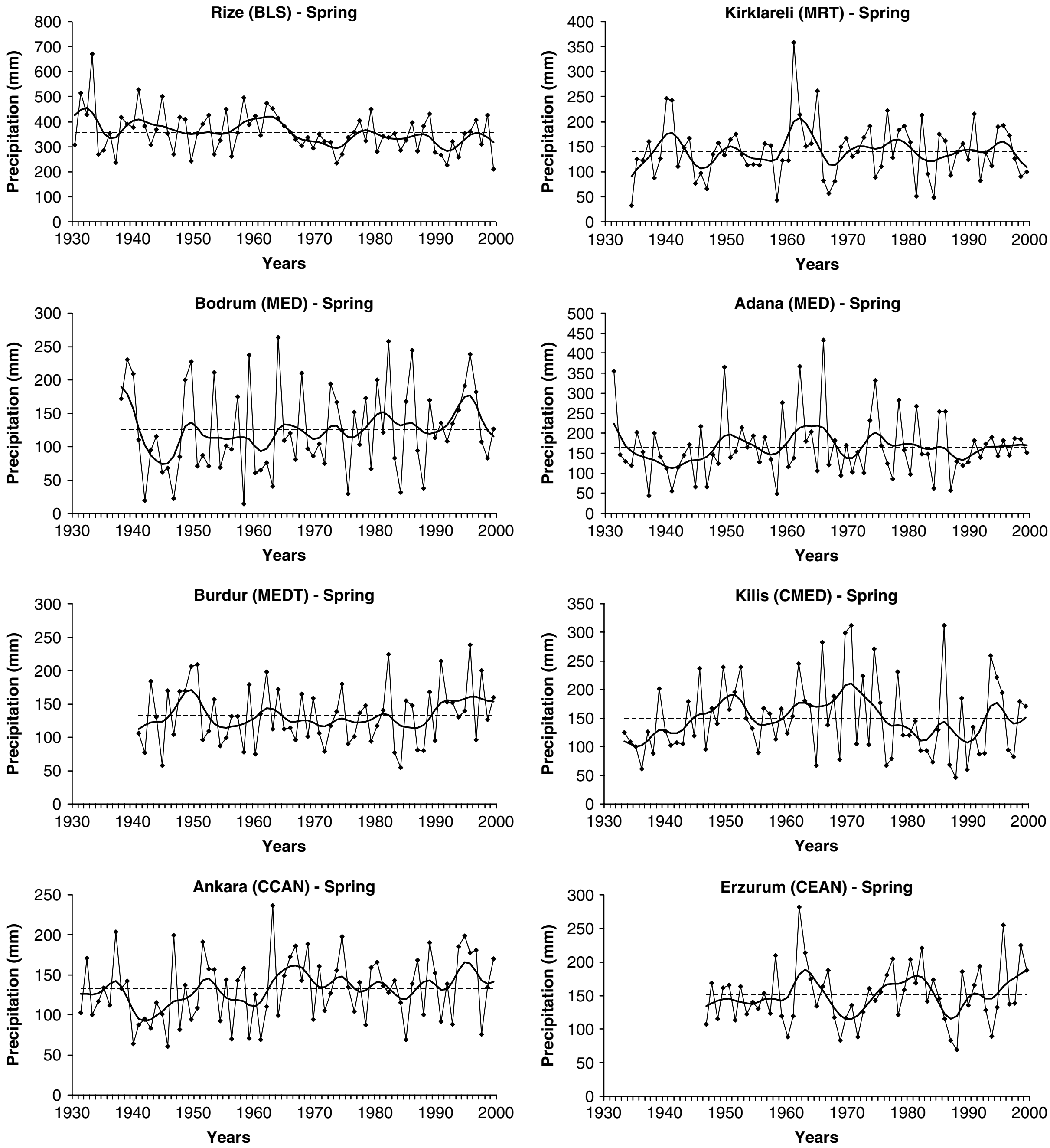

Figure 8. As in Figure 7, but for spring precipitation total series of selected representative stations.

winter precipitation variability in Turkey (Türkeş, 1998; Türkeş *et al*., 2002a; Türkeş and Erlat, 2005). An evident fluctuation with wet and dry sequences is seen at stations of the MRT, MED, MEDT and CMED rainfall regions that are influenced and controlled more or less by the large-scale pressure and wind systems governing the macro Mediterranean climate throughout the year, particularly its rainfall regime and variability. The relatively weak decreasing trend was also found in the CEAN and CCAN rainfall regions, especially in recent years (Figure 7).

In spring, on the other hand, an increasing trend is generally observed in precipitation totals in all rainfall regions except the BLS region (Figure 6(b)). However, results of the $M-K$ significance test show that the majority of the increasing trends determined in precipitation series are statistically random. Only the increasing trends of precipitation totals at three stations are significant at the 5% level of significance. Spring precipitation total series of Turkey clearly indicate a high year-to-year variability (i.e. high-frequency oscillation) that is statistically characterized mostly by a negative autocorrelation (Figure 8). This situation was explained before in detail by Türkeş (1998) and Türkeş *et al*. (2002a).

In summer, although a weak increasing trend is generally observed in the precipitation total time-series over the country with the exception of the western MED and MRT rainfall regions indicating a slight decreasing trend

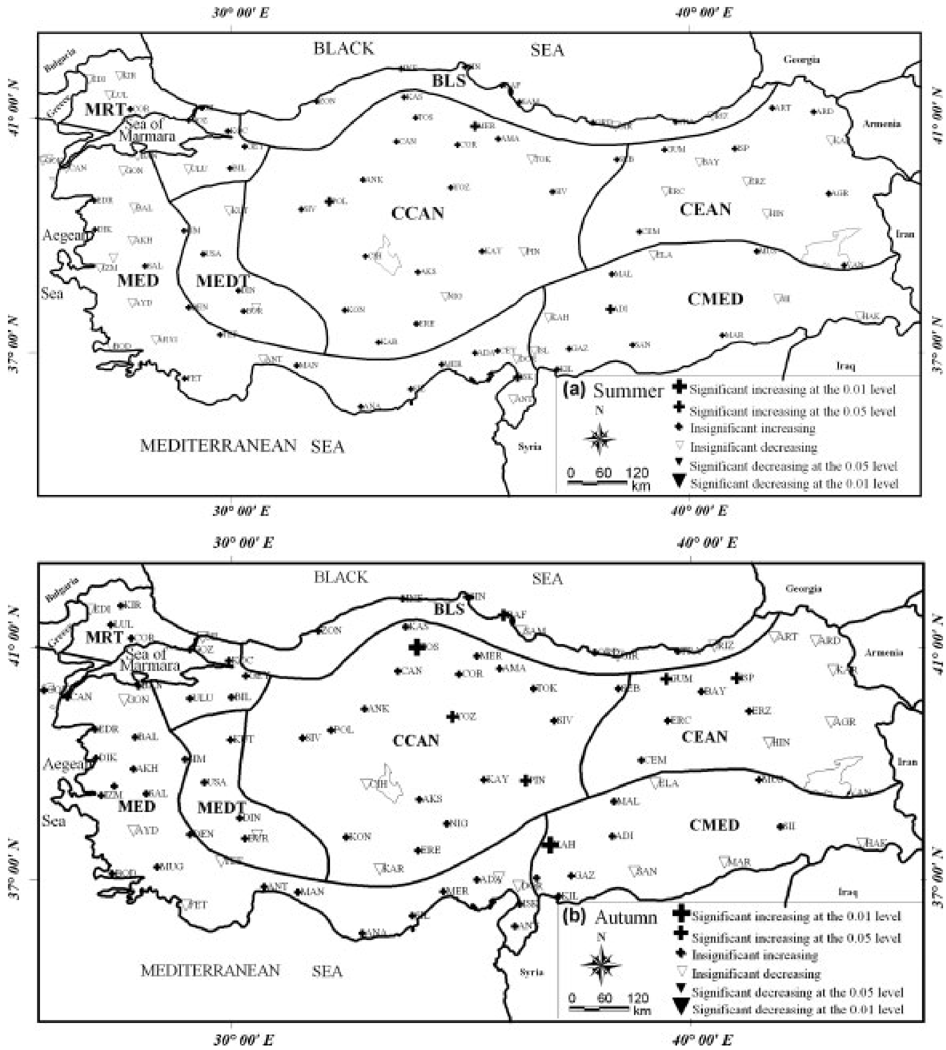

Figure 9. As in Figure 6, but for summer (a) and autumn (b) precipitation series.

at many stations, only four stations have statistically significant increasing trend at the 5% level (Figure 9(a)). The MED rainfall region has a non-significant but slightly decreasing trend at 53% of stations located over this region.

In autumn, precipitation total series of the majority of stations do not show significant trends with the exception of stations located in the northern parts of the CCAN and CEAN rainfall regions of Turkey (Figure 10), and the percentage rate for the number of increasing trends at the stations is greater than those of the decreasing trends. Statistically significant positive trends are found only at five stations, although the increasing trends are dominant with a rate of 68% of the stations used in the study over all rainfall regions (Figure 9(b)).

Annually, precipitation total series of Turkey are generally characterized by both decreasing and increasing trends in Turkey (Figure 11). The number of the stations characterized by a statistically significant decreasing trend are determined as nine according to the M–K test, while significant increasing trends are detected at six stations (Figure 12). The dominant decreasing trend in winter precipitation totals is very likely responsible for the general decrease in annual precipitation total series. Decreasing trends in annual precipitation totals are most pronounced for the MED rainfall region with statistically significant decrease found at five stations, while increasing trends show up at some stations of the MRT and CEAN regions and particularly in the CCAN rainfall region (Figure 12). Statistically significant increasing trends indicate a spatial coherence over the northern part of the CCAN rainfall region.

Because the contribution of winter precipitation to annual precipitation amount is high with the exception of the north-eastern Anatolia sub-region of the country, observed decreasing trend in winter particularly at the stations characterized by a Mediterranean climate in general are particularly important than the other seasons.

4.2.2. *Results for monthly series*

As for the monthly results, there is an apparent decreasing trend in precipitation total series in January, February and September and a substantial increasing trend in April, August and October (Figures not given here). However, the number of stations characterized by significant

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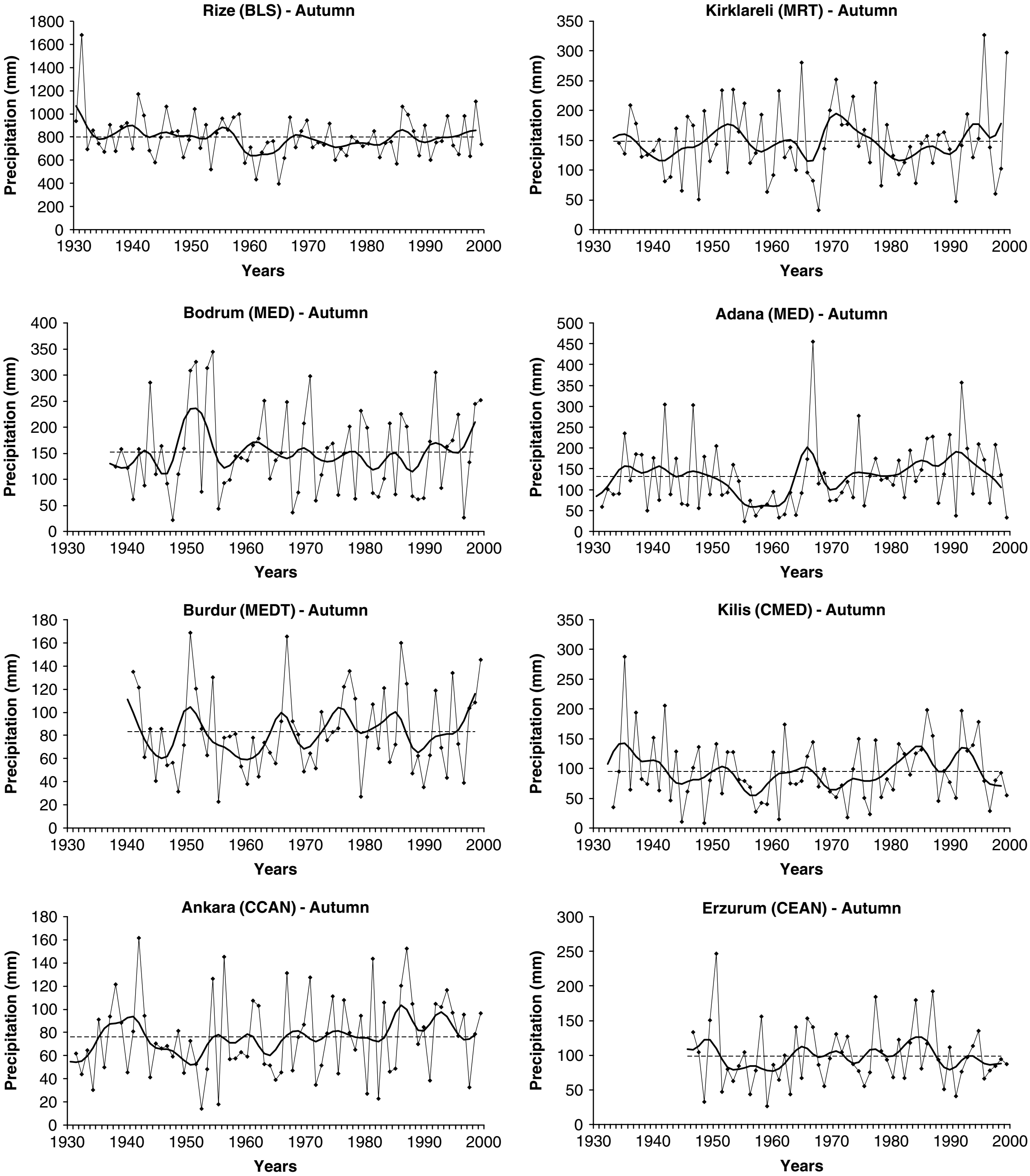

Figure 10. As in Figure 7, but for autumn precipitation total series of selected representative stations.

decreasing trends is greater in January and February with the significant resultant test statistics at 23 and 8 stations, respectively (Tables not given here). The marked decreasing trends in these months are observed particularly in the MED, MEDT, CCAN and CEAN regions. For instance, in January, ten of the stations having a statistically significant decrease in the monthly series are detected in the MED rainfall region. Increasing trends in April, August and October are evident over the MED, MEDT, MRT and CCAN rainfall regime regions. The number of stations characterized by a significant increasing trend at the 5% level are 14 in April and 12 in August.

5. Summary and conclusions

(1) The spatial relations among the precipitation variations of Turkish stations, most of which are principal climatology stations, investigated by the PCA are summarized as follows:
The eigenvalue of PC1 is the highest in winter, and the pattern characterized by the stronger correlations exhibits a large spatial coherence in winter. It also generally explains the variations of spatial relationships in precipitation totals that are closely influenced by large-scale weather systems in west and relatively smaller-scale regional systems in the east, which is

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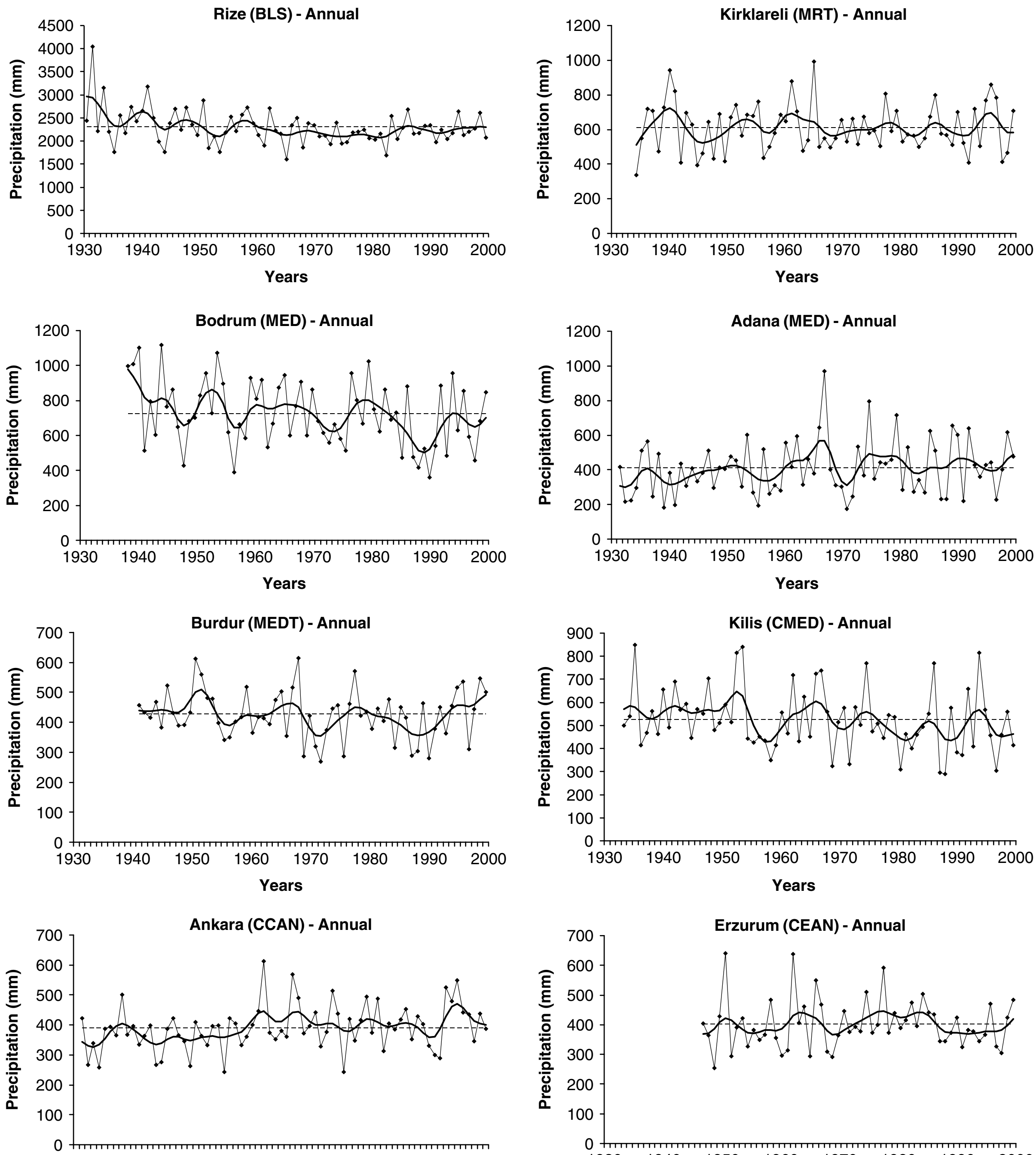

Figure 11. As in Figure 7, but for annual precipitation total series of selected representative stations.

mostly related and/or controlled by the physical geographical factors. A relatively weak correlation pattern is seen over the middle-east and north-eastern Anatolia sub-regions with respect to the influences on occurrence and spatial distribution of the precipitation totals. This situation can be explained by the influence of dominant weather systems associated with the large-scale atmospheric circulation at the western half of the country in general, and forcing effects of the nearly west to east trending high ranges of the Northern Anatolian Mountains, the main Taurus Mountains and the South-eastern Tauruses, respectively, to orographically lift the maritime polar and the Mediterranean air masses over these mountain ranges, respectively.

PC2 of the winter precipitation totals can be characterized by the highest loadings over the CMED and CEAN rainfall regions. The spatial pattern of PC2 very likely explains the influences of the humid-temperate and thus conditionally unstable Mediterranean weather systems on the variability of the spatial relations among the stations over these regions.

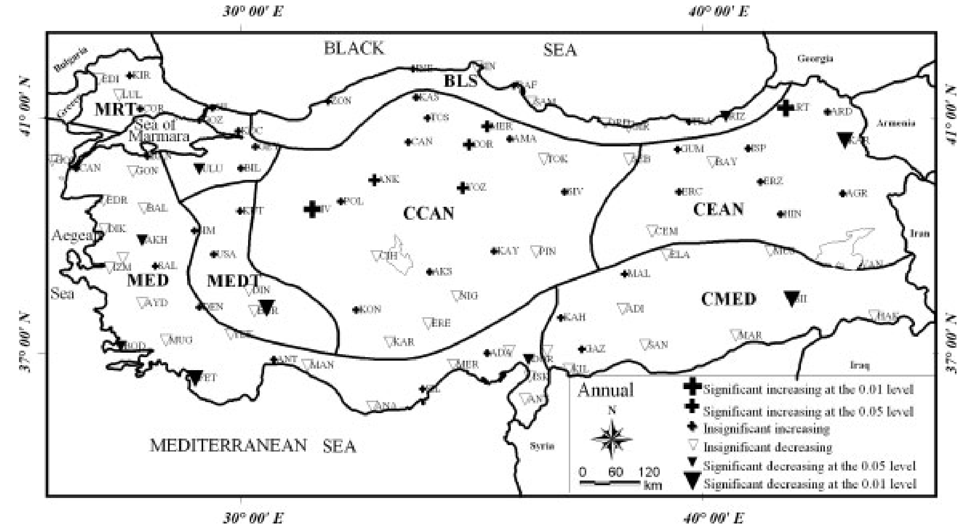

Figure 12. As in Figure 6, but for annual precipitation series.

This information arising from PC2s also consists of the spatial relations of stations that are influenced by continentality, getting stronger from the west towards the mountainous eastern Anatolia region. On the other hand, the PC3 pattern explains the humid-temperate influences of the Mediterranean Sea on the winter precipitation totals by making stronger direct influence of the mid-latitude cyclones over the Aegean portion and Antalya district of the MED region.

In summer, it is very likely that PC1 explains the direct influences of the mid-latitude cyclones related to the large-scale atmospheric circulations reaching from Eastern Europe to Turkey. Loadings of PC2 centre over the western BLS sub-region well explain orographic rainfalls over the region caused by forcing of the north-westerly air flows carrying the Atlantic sourced polar air to the north of Turkey, whereas loadings over the continental type rainfall regions of Turkey along with the Eastern Mediterranean sub-region and the CMED region very likely explain the influences of the intensive showers and thunderstorms related to the regional and/or local convectively unstable conditions over these regions in summer. The PC3 loadings over the rainiest districts of Turkey in summer (i.e. the eastern BLS and north-eastern Anatolia sub-regions) well explain the influences of the coastal orographic and continental convective instability showers and thunderstorms, both of which are closely associated with, and controlled by, northerly sector surface and upper air flows and atmospheric disturbances over the region. Regional surface warming contributes to and strengthens this mechanism in summer season.

(2) Results of the $M-K$ trend analysis are also summarized as follows:

An apparently decreasing trend is dominant in winter precipitation totals, while spring, summer and autumn precipitation totals have a slightly increasing trend. The magnitude of the decreasing trend in annual precipitation totals is smaller than that in winter series, and the significant decreasing trends are most evident in the MED region.

As for monthly precipitation trends, January, February and September precipitation series of Turkey are characterized by an apparent decreasing trend. The decreasing trend is observed particularly in the MED, MEDT, CCAN and CEAN rainfall regions. On the other hand, monthly series show a clear increasing trend especially in April, August and October. Increasing trends are evident in the MED, MEDT, MRT and CCAN rainfall regions.

(3) The results of PCA confirm the climatological results of previous studies (Türkeş, 1996, 1998, 1999, 2003) that explained the general characteristics of precipitation and aridity over Turkey, whereas the results of PCA show a somewhat good agreement with results of the PCA performed by Kadıoğlu (2000). This is very likely due to the fact that we made good use of the knowledge explaining influences of the major physical geographical control mechanisms of Turkey (including regional-scale circulation, topography, land–sea distribution, exposition and continentality) on regional climate or rainfall regime types as the basis for spatial assessments over Turkey. However, the results of the new trend analysis have common points with previous findings concerning Turkey's precipitation such as found by Türkeş (1996, 1998, 1999) and Türkeş and Erlat (2003, 2005). On the other hand, our new results have clearly revealed that decreasing trends in winter precipitation totals and increasing trends in spring and summer totals become stronger and more extensive with respect to both statistical significance and spatial coherence, respectively, compared with previous results of Türkeş (1996, 1998, 1999).

(4) Both the observed decreasing trends in the Mediterranean Basin and Turkey's precipitation in winter

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(Türkeş, 1996, 1998, 2003; Türkeş and Erlat, 2005; Trigo *et al*., 2006), and the rising trend in frequency for the occurrence of low intensity precipitation events (Koç and İrdem, 2005) in Turkey are the most substantial points in terms of the precipitation changes and variability. These have also been indicating increased drying and desertification in the western and southern regions of Turkey, characterized generally by the Mediterranean climate. Decreasing trends in winter precipitation density (Türkeş *et al*., 2007) and precipitation total series are of critical importance in explaining changes to the drought characteristics and vulnerability of Turkey. It is also possible to see a change in seasonal distribution of dry sequences and an extension in their duration. On the other hand, the observed decreasing trend in precipitation totals of the BLS region can be related to a new aspect arising from having increased dry conditions in the humid northern regions of Turkey.

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