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Trend analysis of precipitation data in Turkey and relations to atmospheric circulation: (1955-2013)

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Abstract. Climate change is expected to significantly affect the precipitation regime of the Mediterranean basin where Turkey is located. This study investigates the trends of seasonal and annual precipitation time series of 29 rain gauge stations of the Turkish State Meteorological Service (TSMS) for the period 1955–2013, using two statistical tests based on a simple linear regression model and the well-known Mann-Kendall test. The non-parametric Sen's slope estimator was used to estimate the slope of the trend. The results of the trend analysis at the national scale for the entire period 1955-2013 revealed a clear significant upward trend of 5.5%/decade only for autumn precipitation. No significant trend was found in the annual and other seasonal time series. The investigation of abrupt precipitation changes in the series averaged over Turkey resulted in a distinct significant upward trend in autumn precipitation starting in 1984 and a downward trend in winter precipitation initiating in 1971, which, however, seems to start reversing after 1996. The influence of atmospheric circulation on the precipitation variability in Turkey was assessed using five atmospheric circulation indices: North Atlantic Oscillation Index (NAOI), Mediterranean Oscillation Index (MOI), Mediterranean Circulation Index (MCI), Eastern Mediterranean Pattern Index (EMPI) and North-Sea Caspian Pattern Index (NCPI). The analysis of the circulation indices revealed an important link between precipitation variability in Turkey and some atmospheric teleconnection patterns, expressed mainly by the indices of NAOI and MCI.

Keywords. Trend analysis, precipitation, Turkey, atmospheric circulation.

1. INTRODUCTION

Precipitation is a highly variable climatological element both in space and time (Karabulut and Cosun, 2009). This variability results from changes in atmospheric circulation and complex topographic characteristics and affects many aspects of human life e.g. water resources, aridity and desertification conditions, agriculture (Sariş et al., 2010). The global mean precipitation is likely to increase due to increases in the atmospheric moisture-holding capacity associated with global warming (IPCC, 2007). However, future changes in precipitation will not be uniform. An increase in annual mean precipitation is likely by the end of the 21st century over the high latitudes, the equatorial Pacific and in many mid-latitude wet regions, while a decrease is expected in many mid-latitude and subtropical dry regions (IPCC, 2014). Observations indicate an area-averaged precipitation increase since 1951 over the mid-latitude land areas of the Northern Hemisphere (IPCC, 2014).

The Mediterranean basin is deemed vulnerable to climate changes, due to the diverse topography and its position at the interface between the temperate climate of southern Europe and the arid climate of North Africa (Giorgi and Lionello, 2008). The winter precipitation in the Mediterranean region has experienced an overall decreasing trend during the last few decades (Philandras et al., 2011; Norrant and Douguédroit 2006; Piervitali et al., 1997; Palutikof et al., 1996). The eastern Mediterranean has tended towards drying conditions since the mid 20th century (Feidas et al., 2007; Tomozeiu et al., 2005; Alexandrov et al., 2004).

Turkey exhibits spatial differences in precipitation between the southern coasts and the northern and western regions (Tayanç et al., 2009; Partal and Kahya 2006) and between coastal and mountainous regions (Türkeş 1996; Xoplaki et al., 2000; Kadioglu 2000). Toros et al (1994) used seasonal and annual precipitation data of 68 stations in the west part of Anatolia in Turkey for the period 1930-1992 to show a decline in precipitation after 1982 that was attributed only to a fluctuation in precipitation. Kadioglu (1993) analyzed monthly precipitation data of 18 Turkish stations for the period 1929-1990 and found an overall decrease in winter precipitation and an increase in spring precipitation. Türkeş (1996) have conducted a spatio-temporal analysis of annual precipitation variability using monthly precipitation series from 91 stations in Turkey, during the period 1930–1993. They found a slight decrease in area-averaged annual precipitation series averaged over Turkey. Kadioglu (2000) has found a decrease in winter precipitation for Anatolia and Black Sea region and an increase for Mediterranean coastal regions for the period 1931-1990. Partal and Kahya (2006) applied a trend analysis to long precipitation time series (1929-1993) of 96 stations in Turkey and found a significant decreasing trend in the annual rainfall for southern and western Turkey as well as a the Black Sea coast. In another study, Türkeş et al., (2007), detected downward trends in annual and winter rainfall totals and a general upward trend in the spring, summer and autumn rainfall for the period 1930-2002.

There are many reports on the subject published by public authorities. Toros (2012) examined expected spatio-temporal changes in precipitation time series of 165 Turkish stations for the period 1961 to 2008 in order to assess the impact of climate change on precipitation over Turkey. He found a significant decreasing trend at the 35, 13 and 12% of the stations in the winter, annual and rainy period precipitation totals, respectively, with some oscillations during the examined period (decrease during 1968–1973 and 1998–2008 and increase, during 1973–1981 and 1989–1998). In contrast, a significant increase was detected at the 19, 3 and 4% of the stations in the autumn, rainy period and annual precipitation, respectively. It was concluded that climate dynamics such as the effect of NAO on the tracks of the Mediterranean storms are among the main causes of the precipitation variability in Turkey.

According to Efe et al. (2015), trend analysis of the annual total precipitation for the period 1950-2013 showed a general increasing tendency in precipitation on the coastline, mainly in the regions of Marmara and Black Sea. In contrast, a decreasing trend was found in annual total precipitation inland that could be a sign of evolving drought conditions.

Sensoy et. al. (2013), found decreasing trends during the period 1960-2010 for annual precipitation totals in the northern Turkey, whereas Mediterranean Sea, Aegean Sea and south-eastern Anatolia regions presented decreasing trends. On the other hand, the number of days with heavy precipitation shows an upward trend in most of the stations with the exception of the Southeastern Anatolia and Aegean Sea regions.

Atmospheric circulation is a significant contributor to the precipitation variability in Mediterranean. Many studies have detected an important link between Mediterranean precipitation and various large and regional-scale circulation patterns such a North Atlantic Oscillation (NAO), Mediterranean Circulation (MC), North Sea – Caspian Pattern (NCP) and Mediterranean Oscillation (MO) (Greatbach 2000; Cullen et al., 2000; Visbeck et al., 2000; Trigo et al., 2002; Erlat 2002; Karabork et al., 2002; Xoplaki 2002; Krichak and Alpert 2005; Türkeş and Erlat 2005; Turp 2006; Bachmann 2007; Feidas et al., 2007; Lopez-Moreno et al., 2011; Karakoç and Tagil 2014). The variability of winter precipitation in Turkey (especially in the northern Marmara, northwestern Mediterranean and Central Anatolia) was found to be strictly related to the variability of NAO indices (Türkeş and Erlat 2005, 2006).

This study aims primarily at investigating recent trends in the mean seasonal and annual precipitation observations in Turkey for the longest length of historical homogenous precipitation data available for analysis (1955–2013), using two statistical tests. Another objective is to examine any likely link between precipitation variability in Turkey and atmospheric circulation using five atmospheric circulation indices.

2. STUDY AREA AND DATA ANALYSIS

Turkey has a 1650 km length from the west to the east covering an area from 36° N to 42° N latitude and from 26° E to 45° E longitude. According to first Turkish Geography Association (in Turkish Synonym TCK), the country is divided based on First Turkish Geography Congress (6-21 June 1941) into seven geographic regions: Mediterranean, Black Sea, Aegean, Central, East and South- East Anatolia regions (MEB, 1941). Turkey is considered as a large peninsula because it is surrounded by water (Mediterranean Sea, Aegean Sea and Black Sea). While northeast of Turkey receives large precipitation amounts due to the characteristics of the Black Sea coast, the western, eastern and southern regions get less precipitation. Precipitation is irregularly distributed in mountainous regions. Maximum precipitation occurs in winter, early spring late and autumn due to the depression and frontal activity during this period. The average annual total precipitation ranges from 350-500 mm over central and south eastern Anatolia to 800 mm over the Eastern Anatolia and more than 1000 mm along the western Mediterranean basin (Türkeş 1996 and 2003; Kadıoglu 2000; Ozfidaner 2007).

2.1 Precipitation data

In this study, monthly precipitation records from 29 stations of the Turkish State Meteorological Service (TSMS) covering a period of 59 years (1955-2013) were used (Table 1, Figure 1). Observations have been made using mainly pluviometer-type stations. Rain gauges are bucket type and are of 0.2mm accuracy (Irvem and Ozbuldu, 2019). Based on the station history files, not any significant relocation and systematic and countrywide rain gauge change has been made during the study period (Türkeş 1996).

The choice of these stations was made based on the data length and completeness. Missing monthly values in the precipitation series were few, less than 3 per cent of the total size of the dataset, and were filled out with estimates from surrounding stations according to the normal ratio method (Sing 1992; Türkeş 1998; Feidas et al., 2007). The normal ratio method has a long history and high capability in estimating missing values in rainfall time series. Therefore, due to its simplicity, it is the most commonly used method in imputing missing rainfall records from surrounding stations (Burhanuddin et al., 2017). The

Tab. 1. Metadata of the selected stations.

Station WMO Number	Station Name	Latitude (N)	Longitude (E)	Altitude (m)	Data Length (Years)
17292	Mugla	37.17	28.22	646	59
17370	Iskenderun	36.35	36.10	2	59
17250	Nigde	37.28	34.41	1211	59
17261	Gaziantep	37.40	37.29	854	59
17270	SanliUrfa	37.90	38.47	547	59
17210	Siirt	37.55	41.56	896	59
17220	Izmir	38.23	27.40	20	59
17240	Isparta	37.47	30.34	997	59
17172	Van	38.29	43.23	1670	59
17180	Dikili	39.40	26.53	7	59
17184	Akhisar	38.48	27.50	79	59
17188	Usak	38.68	29.47	929	59
17190	Afyonkarahisar	38.44	30.34	1034	59
17196	Kayseri	38.43	35.29	1092	59
17130	Ankara	39.59	32.41	879	59
17160	Kırsehir	39.90	34.10	1007	59
17084	Corum	40.32	34.56	776	59
17090	Sivas	39.45	37.10	1285	59
17112	Canakkale	40.80	26.23	5	59
17050	Edirne	41.40	26.33	51	59
17056	Tekirdag	40.59	27.29	4	59
17059	Kumkoy	41.25	29.04	38	59
17070	Bolu	40.44	31.36	737	59
17074	Kastamonu	41.22	33.46	800	59
17022	Zonguldak	41.27	31.47	154	59
17024	Inebolu	41.58	33.45	66	59
17030	Samsun	41.21	36.14	4	59
17034	Giresun	40.55	38.23	38	59
17040	Rize	41.20	40.30	8	59

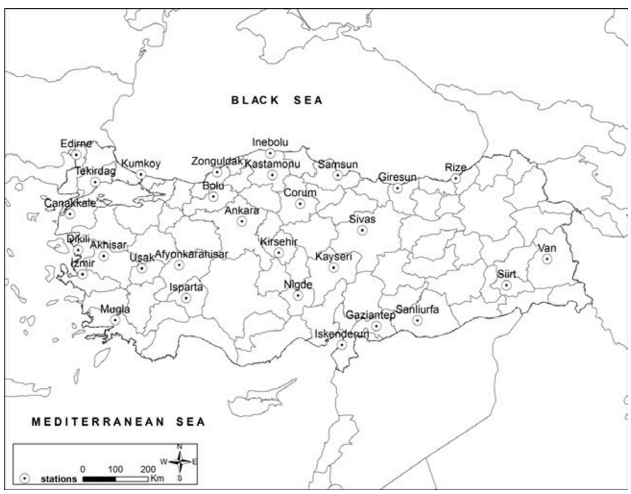

Fig. 1. The locations of the 29 Turkish stations used in the study.

choice of the adjacent reference stations was made based on the highest correlation coefficients (above 0.65 at 95% level of significance), between the station with the missing value and the nearby reference stations.

In order to retain the rainy season as one continuous period, annual precipitation totals were calculated based on a water year, defined as the twelve-month period from September 1 of one given year through August 31 of the next year. Both, annual and winter precipitation was attributed to the year in which January belonged. Finally, precipitation data was expressed as percentage of normal precipitation based on data from 1961 to 1990 period.

The homogeneity of the precipitation records were checked by applying four absolute test methods to the seasonal and annual precipitation series: the Buishand range test, the Bartlett short-cut test, the Levene test and the Von Newmann ratio test (Buishand 1982; Mitchell et al., 1966; Levene 1960; Von Newmann 1941). Although relative tests with respect to homogeneous neighboring stations are deemed to be much more efficient than absolute tests that relies only on a single station climate series (Peterson et al., 1998), these tests are not considered suitable for the precipitation records of this study due to the low correlation of precipitation data of neighboring stations and the sparse station network. The null hypothesis states that precipitation data of a time series are random variables identically and independently distributed whereas the alternative hypothesis assumes that the series is not randomly distributed with the exception of the Buishand range test in which the alternative hypothesis assumes the presence of a step-wise shift in the mean (called as a break). The Buishand test has the advantage of being able to locate the year of a likely break (Feidas et al., 2007).

The next step is to apply the Schönwiese and Rapp (1997) classification in which a data series is labelled 'suspect' when more than two tests reject the null hypothesis at the 5% significance level. A 'suspect' series is considered inhomogeneous and is not used in the trend analysis. According to the results of the homogeneity tests, all the precipitation series of the 29 stations were characterized as homogeneous.

The existence of possible trends in the seasonal and annual precipitation time series was investigated using two statistical tests: a simple parametric linear regression model and the non-parametric Mann-Kendall statistic test (Sneyers, 1990). Linear trends are considered to be significant at the 95% confidence level when found as such by both statistics t and $u(d_n)$.

In the first test, the null hypothesis that the slope b of the regression line is zero is rejected using the value of the t-test statistic $t = \hat{b}/\hat{s}_1(\hat{b})$, where $\hat{s}_1(\hat{b})$ is the standard error of slope b. The second test is considered the most suitable not only for trend analysis of climate data but also for detecting a climatic discontinuity in the data series (Goosens and Berger, 1986). The null hypothesis of zero slope b of the regression line is rejected when the final (for $i = n$) absolute value $u(d_n)$ of the statistic series $u(d_i)$ is greater than 1.96 at 95% level of confidence, where n is the data series size. The plot of all $u(d_i)$ and its retrograde series $u'(d_i)$, for $1 \leq i \leq$ n, is marked as C_1 and C_2, respectively. The intersection of curves C_1 and C_2 denotes the starting year of the trend or climate change.

The non-parametric Sen's slope estimator (Sen, 1968) was used to estimate the slope b (mm/year) of the trend line, given that precipitation amounts are typically not normally distributed. It is a robust non-parametric method that is insensitive to outliers and it does not draw from any probability distribution. The method estimates the slope by choosing the median of the slopes of all lines through pairs of points. The upper (b_u) and lower (b_l) limits for the slope are also computed at the 95% confidence level.

The Sen's slope b was expressed as well as %/decade by computing the average decadal percent change. A log-level regression $\ln(y) = a + b$t was run between precipitation values (y) and time (t) in tin years intervals to estimate the average decadal percent change as $\exp(b) - 1$, where b is the regression coefficient of the equation $\ln(y) = a + b\times$ t (Clegg et al., 2009).

2.2 Circulation indices

In order to assess the relation of precipitation in Turkey with large-scale and regional atmospheric circulation, five circulation indices were used:

(a) the North Atlantic Oscillation Index (NAOI), which uses the surface pressure difference between stations in the subtropical high of Azores and the subpolar Icelandic low pressure system (Walker 1924; Walker and Bliss 1932; Rogers and van Loon 1979),

(b) the Mediterranean Oscillation Index (MOI), calculated as the difference of standardized anomalies of the 500 hPa geopotential height field between western and eastern parts (usually the stations of Algiers and Cairo) of the Mediterranean basin (Conte et al., 1989; Colacino and Conte 1993; Kutiel et al., 1996; Douguedroit 1998; Maheras et al., 1999; Maheras and Kutiel 1999; Piervitali et al., 1999; Criado-Aldeanueva and Soto-Navarro 2013),

(c) the Mediterranean Circulation Index (MCI), expressed as the standardized mean sea level pressure difference between two stations (Marseille and Jerusalem) located in the northwestern and southeastern Mediterranean (Brunetti et al., 2002),

(d) the Eastern Mediterranean Pattern Index (EMPI), which is a seesaw pattern between the eastern Mediterranean basin and northeastern Atlantic ocean at the 500 hPa surface (Hatzaki et al., 2007), and

(e) the North-Sea Caspian Pattern Index (NCPI), expressed as the normalized difference between averages of the 500 hpa geopotential height of two areas located at the North Sea (0°E, 55°N and 10°E, 55°N) and North Caspian Sea (50°E, 45°N and 60°E, 45°N) (Kutiel and Benaroch 2002).

Monthly values of NAOI for the period of interest (1955–2013) were acquired from the database of the National Center of Atmospheric Research (NCAR) whereas the other five indices were calculated using the gridded reanalysis dataset of the National Center for Environmental Prediction (NCEP) of NCAR. The relationship of the precipitation variability in Turkey with atmospheric circulation was assessed based on the Pearson correlation coefficients between the data series of the teleconnection indices and the precipitation averaged over Turkey.

3. RESULTS AND DISCUSSION

3.1 Precipitation trends

Trend analysis of precipitation time series in Turkey was performed by applying the two statistical tests (a parametric regression-based model and the non-parametric Mann-Kendall test) to the seasonal and annual precipitation series of the 29 Turkish stations for the period 1955–2013.

The non-parametric Sen's slope estimator (Sen, 1968) was applied to estimate the magnitude of the linear trends expressed with the slope b of the regression line. Table 2 presents the values of the slope b in mm/year, the lower b_l and upper b_u slope limits at the 95% confidence level and the statistics t and $u(d_n)$ for the seasonal and annual precipitation series. Linear trends (b) are deemed to be significant at the 95% confidence level when found as such by both statistics t and $u(d_n)$. These significant cases are indicated in Table 2 with boldface characters. The Sen's slope b expressed as well as %/decade along with its upper (b_u) and lower (b_l) limits at the 95% confidence level is presented in Table 3.

Seasonal and annual precipitation time series, trend line and its lower and upper limits at the 95% confidence level were plotted and analyzed for each of the 29 stations. Figure 2 presents an example with the graphs for Sivas station.

The spatial distribution of the sign and statistical significance of the Sen's slope b estimates of the trend line for the seasonal and annual precipitation time series of the 29 stations is presented in Figure 3. Squares indicate positive values and circles denote negative slope values. Figure 3 and Table 2 and 3 combined can be used to locate positive or negative trends of the stations' time series and assess their spatial distribution.

On an individual station level, significant trends are found mainly in autumn and annual time series. Prevalent increasing trends were observed for the autumn time series with 9 out of 29 statistically significant stations, located mainly in central Anatolia. The average percent decadal change ranges from 8.6% to 14.7% per decade (Table 3). Only three stations (Gaziantep, Sivas and Kastamonu) were found to have small but statistically significant (upward) trends in the annual time series in the range 3.8–4.9%. Only one station exhibited statistically significant trend in winter (Isparta) and summer (Samsun) but with opposite signs (downward and upward, respectively) and magnitudes (-6.5% and 11.9% per decade, respectively).

Concerning the neighboring of different sign of changes (positive and negative), this exists only in no statistically significant cases. Moreover, the large geomorphic diversity of landscapes in Turkey can explain such spatial differences in the start and the sign of a change, even if trends are not statistically significant.

In order to have a representation of the country as a whole, precipitation series of the 29 Turkish stations were spatially averaged to estimate precipitation trends at the national scale. Precipitation was expressed as percentage of the normal based on data of the 1961 - 1990 period to facilitate merging and prevent any trend from being prevailed by highly variable time series (Feidas et al., 2007). The results of the trend analysis for these area averaged time series are presented in Table 2 (last row) and plotted in Figure 4. Table 2 and Figure 4 indicate that only autumn precipitation spatially averaged over Turkey present a distinct significant upward trend of 5.5%/decade. No clear significant trend was detected in the annual and other seasonal series.

The $u(d_i)$ and $u'(d_i)$ statistics of the sequential Mann-Kendall test were plotted for the precipitation series of each station and the regional mean series for Turkey, in order to locate the beginning of a trend or change based on the intersection of the curves C_1 and C_2. Plots for Sivas station and Turkey as a whole are given in Figure 5 and 6, respectively. This graphical analysis was performed on the full range of the 29 stations to locate any likely trend statistically significant at the 95% confidence level and the time of an abrupt precipitation change. The increasing (+) and decreasing (-) trends and the approximate year of the initiation of the trend for the seasonal and annual series are provided in Table 4. The second year in some stations indicates a not statistically significant new change in the trend. The asterisk connotes the absence of a statistically significant trend for the period 1955-2013.

Table 4 shows a clear evidence of trends only for winter and autumn precipitation series. More precisely, a downward trend for winter series initiated during the

Tab. 2. Trend analysis results of the application of the two statistical tests on the seasonal and annual precipitation series over the period 1955-2013[a] (Statistically significant cases at the 95% confidence level, provided by both tests, are indicated with boldface characters).

Station	Winter					Spring					Summer					Autumn					Annual				
	b	b_l	b_u	t	$u(d_n)$	b	b_l	b_u	t	$u(d_n)$	b	b_l	b_u	t	$u(d_n)$	b	b_l	b_u	t	$u(d_n)$	b	b_l	b_u	t	$u(d_n)$
Iskenderun	0.60	-1.29	2.26	0.30	0.67	-0.65	-1.93	0.45	-1.22	-1.07	0.66	0.12	1.16	1.92	2.30	0.83	-0.20	1.94	1.14	1.57	1.75	-0.73	4.24	0.75	1.33
Kumkoy	0.80	-0.76	2.20	0.35	0.92	-0.05	-0.76	0.78	-0.19	-0.14	0.03	-0.70	0.85	0.39	0.06	**2.00**	**0.70**	**3.19**	**2.60**	**2.48**	2.46	-0.30	5.02	1.75	1.76
Mugla	-2.65	-6.61	0.94	-1.43	-1.56	0.46	-0.95	1.95	0.48	0.67	0.13	-0.20	0.54	1.07	0.84	1.24	-0.17	2.48	1.82	1.70	-0.43	-5.35	3.60	-0.42	-0.21
Izmir	-0.02	-2.16	2.15	-0.21	-0.02	0.28	-0.69	1.23	0.74	0.62	-0.04	-0.15	0.06	-0.12	-0.95	**1.43**	**0.16**	**2.64**	**2.83**	**2.38**	1.72	-0.79	4.30	1.46	1.45
Dikili	-1.21	-3.27	0.67	-1.59	-1.37	-0.10	-0.88	0.74	0.28	-0.27	0.07	-0.09	0.23	1.17	0.87	0.33	-0.64	1.32	0.70	0.66	-1.12	-3.69	1.16	-0.95	-0.90
Gaziantep	0.55	-0.93	2.08	0.93	0.49	0.19	-0.98	1.36	0.25	0.32	0.01	-0.10	0.15	0.88	0.26	**1.12**	**0.36**	**1.99**	**2.38**	**2.37**	**2.12**	**0.10**	**3.94**	**2.12**	**2.11**
Sanliurfa	-0.97	-2.25	0.23	-1.40	-1.50	-0.37	-1.50	0.51	-0.99	-0.92	0.00	-0.01	0.06	0.70	0.75	0.36	-0.20	1.04	1.08	1.05	-0.75	-2.43	0.72	-1.17	-1.09
Siirt	-0.02	-1.60	1.43	-0.47	-0.06	-0.64	-1.78	0.99	-0.81	-0.56	0.08	-0.06	0.22	1.17	0.90	0.07	-0.89	1.06	0.29	0.10	-0.20	-2.75	2.43	-0.39	-0.11
Isparta	**-1.43**	**-2.98**	**-0.16**	**-2.24**	**-2.28**	-0.01	-0.87	0.84	-0.14	-0.03	0.20	-0.37	0.73	0.46	0.73	0.27	-0.41	0.83	1.19	0.97	-0.92	-3.2	0.92	-1.25	-0.96
Afyonkarahisar	0.18	-0.50	0.91	0.88	0.35	-0.17	-0.85	0.54	-0.54	-0.52	-0.11	-0.67	0.45	-0.39	-0.27	0.48	-0.08	0.99	1.37	1.67	0.75	-0.45	2.08	0.87	1.21
Usak	-0.20	-1.54	1.17	-0.25	-0.23	0.23	-0.59	1.02	0.78	0.71	-0.02	-0.48	0.46	-0.28	-0.14	0.77	0.14	1.29	1.48	2.07	0.85	-0.92	2.41	0.91	1.07
Akhisar	-1.04	-2.55	0.64	-1.61	-1.27	-0.07	-0.84	0.71	-0.13	-0.11	-0.12	-0.35	0.12	-0.68	-0.92	**0.84**	**-0.14**	**1.80**	**3.17**	**3.00**	-0.27	-2.29	1.56	-0.64	-0.23
Nigde	0.03	-0.56	0.64	0.28	0.03	-0.22	-0.93	0.51	-0.63	-0.57	0.21	-0.10	0.53	1.32	1.26	**0.82**	**0.40**	**1.23**	**4.34**	**3.85**	0.58	-0.53	1.74	1.65	0.95
Kayseri	-0.02	-0.55	0.49	0.41	-0.02	0.32	-0.31	1.02	1.02	0.87	-0.08	-0.58	0.44	-0.03	-0.23	**0.56**	**0.09**	**1.08**	**2.04**	**2.30**	0.97	-0.17	2.29	1.58	1.75
Ankara	-0.23	-0.92	0.54	-0.99	-0.47	0.07	-0.57	0.76	0.33	0.12	-0.09	-0.62	0.42	-0.31	-0.44	0.40	-0.22	1.01	1.16	1.23	0.46	-0.82	1.75	0.28	0.77
Kirsehir	-0.60	-1.30	0.10	-1.39	-1.52	-0.17	-0.91	0.60	-0.12	-0.46	-0.02	-0.53	0.44	-0.07	-0.15	**0.86**	**0.36**	**1.50**	**3.05**	**2.90**	0.18	-1.01	1.58	0.57	0.28
Corum	-0.13	-0.89	0.61	-0.64	-0.30	0.08	-0.66	0.64	0.10	0.32	0.31	-0.51	1.08	1.03	0.77	**0.87**	**0.31**	**1.43**	**2.34**	**3.03**	1.06	-0.16	2.40	1.80	1.80
Sivas	0.26	-0.33	0.92	0.84	0.94	0.52	-0.14	1.18	1.42	1.48	0.08	-0.36	0.55	0.13	0.35	**1.10**	**0.55**	**1.63**	**3.81**	**3.63**	**1.97**	**0.65**	**3.11**	**3.19**	**2.84**
Van	0.25	-0.38	0.78	0.82	0.84	-0.10	-0.74	0.55	-0.31	-0.37	0.02	-0.25	0.30	0.19	0.12	0.21	-0.39	0.92	0.26	0.65	0.56	-0.77	1.88	0.78	0.86
Canakkale	-0.78	-2.88	0.86	-1.06	-1.22	-0.16	-0.91	0.62	-0.12	-0.37	0.01	-0.45	0.41	-0.83	0.05	-0.30	-1.34	0.86	-0.05	-0.47	-0.95	-3.25	1.38	-1.05	-0.67
Edirne	-0.30	-1.62	1.10	0.01	-0.48	-0.54	-1.19	0.23	-1.01	-1.34	-0.30	-1.01	0.62	-0.70	-0.52	0.29	-0.62	1.35	0.93	0.70	-0.73	-2.66	1.50	-0.15	-0.67
Tekirdag	-0.40	-1.79	0.84	-0.44	-0.69	-0.24	-1.02	0.51	-0.62	-0.50	-0.27	-0.74	0.30	-0.62	-0.97	0.71	-0.67	1.97	1.04	0.99	-0.29	-2.52	1.86	0.05	-0.28
Bolu	-0.16	-0.98	0.48	-0.83	-0.83	0.42	-0.39	1.10	1.05	1.04	0.09	-0.75	-.92	0.16	0.19	0.32	-0.23	0.93	0.76	1.16	0.40	-1.15	2.09	0.66	0.62
Kastamonu	0.23	-0.40	0.85	0.73	0.76	0.46	-0.38	1.21	1.08	1.09	0.51	-0.59	1.56	1.52	0.83	0.54	-0.04	1.13	1.37	1.81	**1.70**	**0.16**	**3.22**	**2.63**	**2.19**
Zonguldak	-0.54	-1.65	0.74	-0.94	-0.85	-0.65	-1.47	0.44	-1.01	-1.01	-0.42	-1.74	1.30	0.23	-0.49	1.76	0,05	3.40	1.76	2.02	0.43	-2.24	3.30	0.68	0.32
Inebolu	-0.01	-1.29	1.51	-0.10	-0.03	0.27	-0.73	1.16	0.49	0.57	0.08	-0.94	1.20	0.36	0.18	0.70	-0.50	2.21	2.01	1.11	2.17	-0.60	4.74	1.37	1.47
Samsun	-0.38	-1.42	0.59	-0.96	-0.79	-0.21	-0.96	0.59	-0.48	-0.49	**1.18**	**0.18**	**2.00**	**2.59**	**2.24**	0.70	-0.53	1.75	0.36	0.98	1.62	-0.61	3.60	1.24	1.39
Giresun	-0.28	-1.74	0.86	-1.01	-0.44	-0.11	-1.03	0.83	-0.42	-0.29	0.50	-1.21	1.76	0.91	0.50	1.32	-0.57	3.19	2.15	1.43	1.31	-0.57	3.19	1.11	1.45
Rize	-0.53	-2.44	1.43	-0.55	-0.69	-0.86	-2.00	0.27	-1.36	-1.54	0.52	-1.56	2.04	0.52	0.48	1.99	-0.43	5.04	1.47	1.64	2.73	-2.34	7.72	0.83	1.16
Turkey	-0.28	-1.12	0.61	-0.80	-0.46	-0.08	-0.51	0.40	-0.24	-0.37	0.15	-0.20	0.49	1.00	0.83	**0.94**	**0.45**	**1.36**	**3.35**	**3.38**	0.91	-0.32	1.94	1.07	1.42

[a] b (mm/year) is the Sen's slope estimates of the trend line, b_l and b_u are the lower and upper slope limits at the 95% confidence level, t is the statistic of the linear regression model and $u(d_n)$ is the final value (for $i = n$) of the Mann-Kendall statistic.

Tab. 3. Sen's slope estimates (b) for the trend of seasonal and annual precipitation series over the period 1955-2013, expressed as average percent change per decade. b_l and b_u denotes the lower and upper slope limits at the 95% confidence level (Statistically significant cases, provided by both tests, are indicated with boldface characters).

Station	Winter			Spring			Summer			Autumn			Annual		
	b (%)	b_l (%)	b_u (%)	b (%)	b_l (%)	b_u (%)	b (%)	b_l (%)	b_u (%)	b (%)	b_l (%)	b_u (%)	b (%)	b_l (%)	b_u (%)
Iskenderun	2.3	-4.6	9.6	-2.9	-8.6	2.2	17.8	2.7	43.8	4.5	-1.0	11.4	2.5	-1.0	6.2
Kumkoy	2.8	-2.5	8.2	-0.3	-4.9	5.4	0.4	-8.8	11.6	**8.9**	**3.1**	**15.0**	3.2	-0.4	6.7
Mugla	-4.0	-9.6	1.5	2.2	-4.2	9.4	5.7	-6.7	28.1	6.1	-0.7	12.7	-0.4	-4.4	3.2
Izmir	0.0	-5.7	6.4	2.1	-4.5	9.6	-6.3	-27.7	8.5	**10.4**	**1.1**	**20.9**	2.6	-1.2	6.5
Dikili	-3.8	-9.6	2.2	-0.8	-6.1	5.8	7.5	-7.7	29.7	2.6	-4.7	10.3	-1.9	-5.9	2.0
Gaziantep	2.1	-3.1	8.3	1.3	-6.4	10.1	1.3	-10.0	22.3	**12.6**	**3.9**	**25.8**	**4.0**	**0.2**	**7.8**
Sanliurfa	-4.1	-9.0	1.0	-3.2	-11.4	4.7	1.5	-8.7	56.3	5.8	-2.9	18.2	-1.7	-5.3	1.6
Siirt	-0.1	-5.9	5.5	-1.4	-6.4	4.0	8.2	-5.6	37.3	0.7	-7.6	10.2	-0.3	-3.8	3.8
Isparta	**-6.5**	**-12.8**	**-0.8**	-0.1	-5.4	5.6	4.6	-6.5	18.1	3.1	-4.5	10.7	-1.8	-5.7	1.7
Afyonkarahisar	1.5	-4.0	8.1	-1.2	-5.9	4.2	-1.7	-9.8	8.5	6.5	-0.9	14.9	1.8	-1.1	5.3
Usak	-1.0	-7.3	5.7	1.5	-3.7	7.0	-0.4	-9.2	10.6	7.7	1.4	13.9	1.7	-1.7	4.7
Akhisar	-3.7	-8.9	2.4	-0.5	-5.7	5.4	-6.3	-19.0	7.1	**8.9**	**3.1**	**15.0**	-0.5	-3.9	2.8
Nigde	0.3	-5.3	6.7	-1.7	-6.4	4.5	6.5	-3.3	22.2	**14.5**	**7.0**	**24.5**	1.8	-1.6	5.3
Kayseri	-0.2	-4.8	4.9	2.3	-2.2	7.2	-1.6	-10.4	9.3	**8.6**	**1.3**	**19.3**	2.6	-0.4	6.2
Ankara	-1.9	-6.9	4.8	0.5	-4.0	5.8	-1.7	-10.6	8.9	5.8	-2.7	14.6	1.2	-2.0	4.6
Kirsehir	-4.5	-9.6	0.8	-1.5	-7.1	5.3	-0.5	-11.8	12.8	**13.2**	**5.4**	**27.6**	0.5	-2.6	4.4
Corum	-1.1	-7.4	5.7	0.5	-4.2	4.7	4.1	-7.1	14.9	**11.4**	**3.9**	**21.0**	2.4	-0.3	5.8
Sivas	2.1	-2.5	7.9	3.4	-0.8	8.2	1.6	-7.1	14.2	**14.7**	**7.2**	**25.1**	**4.9**	**1.5**	**7.8**
Van	2.6	-3.8	8.6	-0.6	-4.8	4.0	0.7	-10.3	14.1	1.8	-3.4	8.9	1.5	-1.9	5.2
Canakkale	-2.8	-9.8	3.5	-1.2	-6.5	4.7	0.4	-11.3	15.7	-2.0	-7.6	5.8	-1.5	-5.3	2.2
Edirne	-1.7	-8.6	6.6	-3.6	-7.5	1.6	-3.3	-10.5	7.0	2.0	-4.0	10.1	-1.3	-4.5	2.7
Tekirdag	-2.0	-8.1	4.5	-1.8	-6.8	4.1	-4.5	-11.4	5.5	4.5	-3.7	14.8	-0.5	-4.2	3.3
Bolu	-1.0	-5.5	3.0	2.7	-2.3	7.4	0.8	-6.9	9.6	2.9	-2.0	8.7	0.7	-2.1	3.9
Kastamonu	2.8	-4.0	10.7	3.0	-2.4	8.4	4.3	-4.8	13.5	6.4	-0.5	15.4	**3.8**	**0.4**	**7.4**
Zonguldak	-1.3	-4.0	2.0	-3.0	-6.5	2.1	-2.3	-8.5	7.0	4.6	0.2	9.7	0.4	-1.8	2.9
Inebolu	0.0	-3.8	4.8	1.6	-3.9	7.4	0.7	-7.1	10.1	2.0	-1.3	6.7	2.2	-0.6	4.8
Samsun	-1.9	-6.7	3.2	-1.2	-5.6	3.7	**11.9**	**1.7**	**20.8**	3.4	-2.6	9.3	2.4	-0.9	5.3
Giresun	-0.8	-4.8	2.7	-0.5	-4.3	3.8	2.1	-5.1	7.9	3.2	-1.3	8.1	3.2	-1.3	8.1
Rize	-0.8	-3.6	2.3	-2.5	-5.6	0.8	1.2	-3.3	4.7	2.7	-0.5	7.1	1.2	-1.0	3.6
Turkey	-1.1	-4.3	2.5	-0.5	-2.9	2.4	2.1	-2.4	6.2	**5.5**	**2.6**	**8.1**	1.3	-0.5	2.9

decade of 1970s in almost one third of the stations. There are only two neighboring stations (Zonguldak and Samsun) whose downward trend began earlier, during 1960s. On the contrary, an upward trend dominates almost the half of the stations for autumn but with approximate years of the initiation ranging from early 1960s to early 1980s. There is only a small number of stations presenting a statistically significant trend for summer (one station) and spring season (four stations). There is not any clear signal for annual series, with only one third of the stations showing a statistically significant trend starting during 1960s but with opposite signs. In particular, five stations located in western Turkey show positive trends starting between 1960 and 1970 whereas five stations situated in northern and central Turkey exhibit negative trends beginning during the period 1957-1972. It should be noted that the detection of the beginning of a change in the time series is indicative and approximate as it is based on the graphical analysis of the Mann-Kendall rank statistics.

The graphical analysis of the Mann-Kendall statistics implemented to the regional mean precipitation series for the area of Turkey (see last row of Table 4 and Figure 6) supports the previous findings. In particular, autumn shows an upward trend starting in 1984, whereas winter exhibits a downward trend initiating in 1971 which, however, seems to start reversing after 1996. No trend has been found for annual and other seasonal precipitation series.

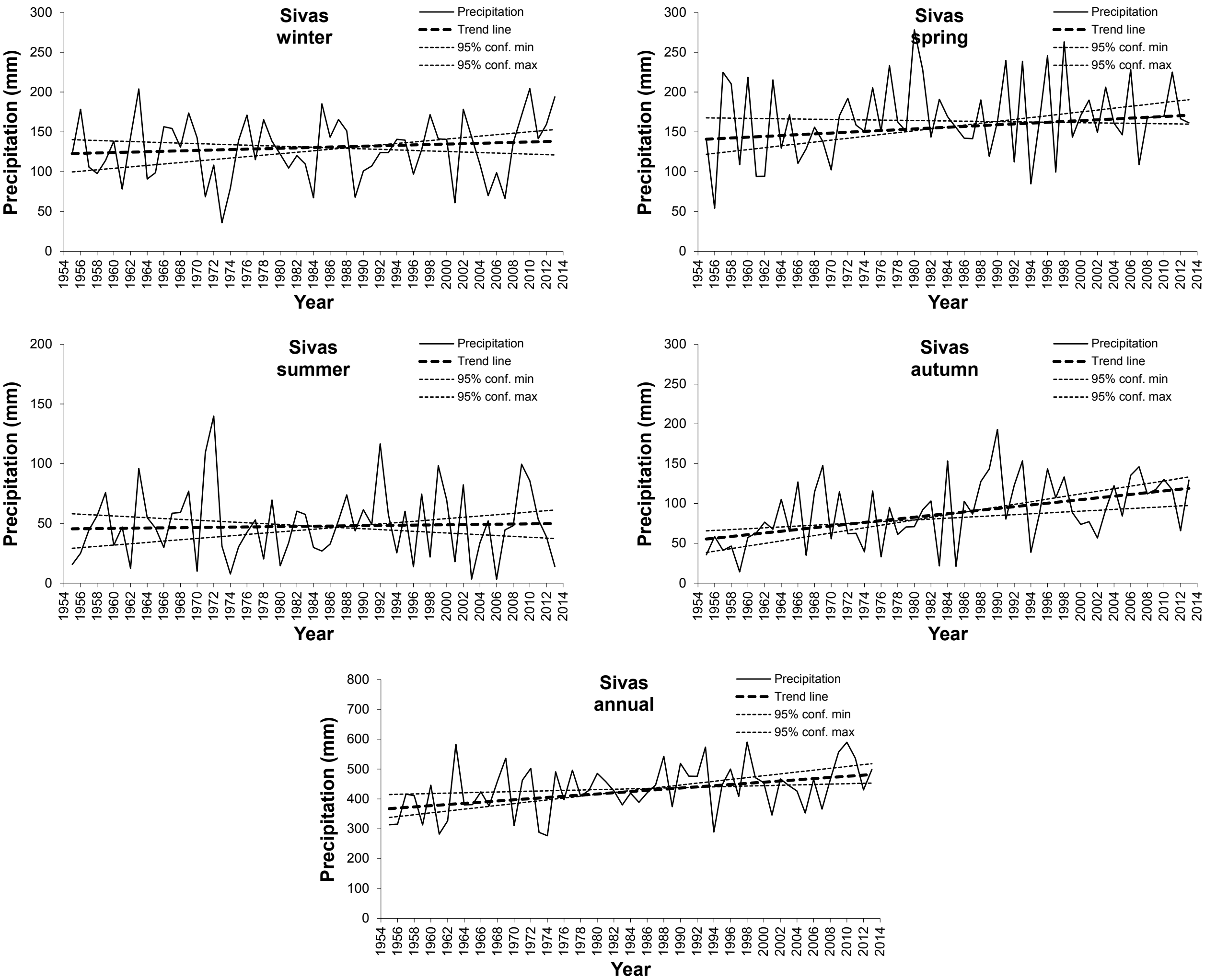

Fig. 2. Seasonal and annual precipitation totals, trend line and its lower and upper limits at the 95% confidence level at the station of Sivas (1955–2013).

These findings are in agreement with other studies partly dealing with precipitation trends in the wider area (Feidas and Lalas 2001; Türkeş et al., 2007; Feidas et al., 2007; Karabulut and Cosun 2009; Philandras et a.,l 2011; Şimşek et al., 2013; Çiçek and Duman 2015).

3.2 Relation of circulation indices with precipitation in Turkey

Table 5 presents the Pearson correlation coefficients between the five circulation indices (NAOI, MOI, MCI, EMPI and NCPI) and the seasonal and annual precipitation percentages, spatially averaged over Turkey.

The important influence of the NAO on the winter precipitation in Turkey is highlighted by the highest and statistically significant negative correlation coefficient (r = - 0.45), with the percentage of the explained winter precipitation variance being up to 20%. A smaller proportion of the winter precipitation variability can be also explained by the NCPI (15%) and EMPI (10%). The MCI plays the most important role in the summer and autumn precipitation accounting for 22% (r = -0.47) and 14% (r = -0.37) of the precipitation variance, respectively. Only a small proportion of the spring precipitation variance (14%) is explained by the EMPI. No significant correlation has been found between the annual precipitation and any of the atmospheric circulation indices. Figure 7 presents the best correlation between seasonal precipitation in Turkey and atmospheric circulation indices.

The previous results suggest the important role of the NAOI and MCI on the winter and summer precipitation

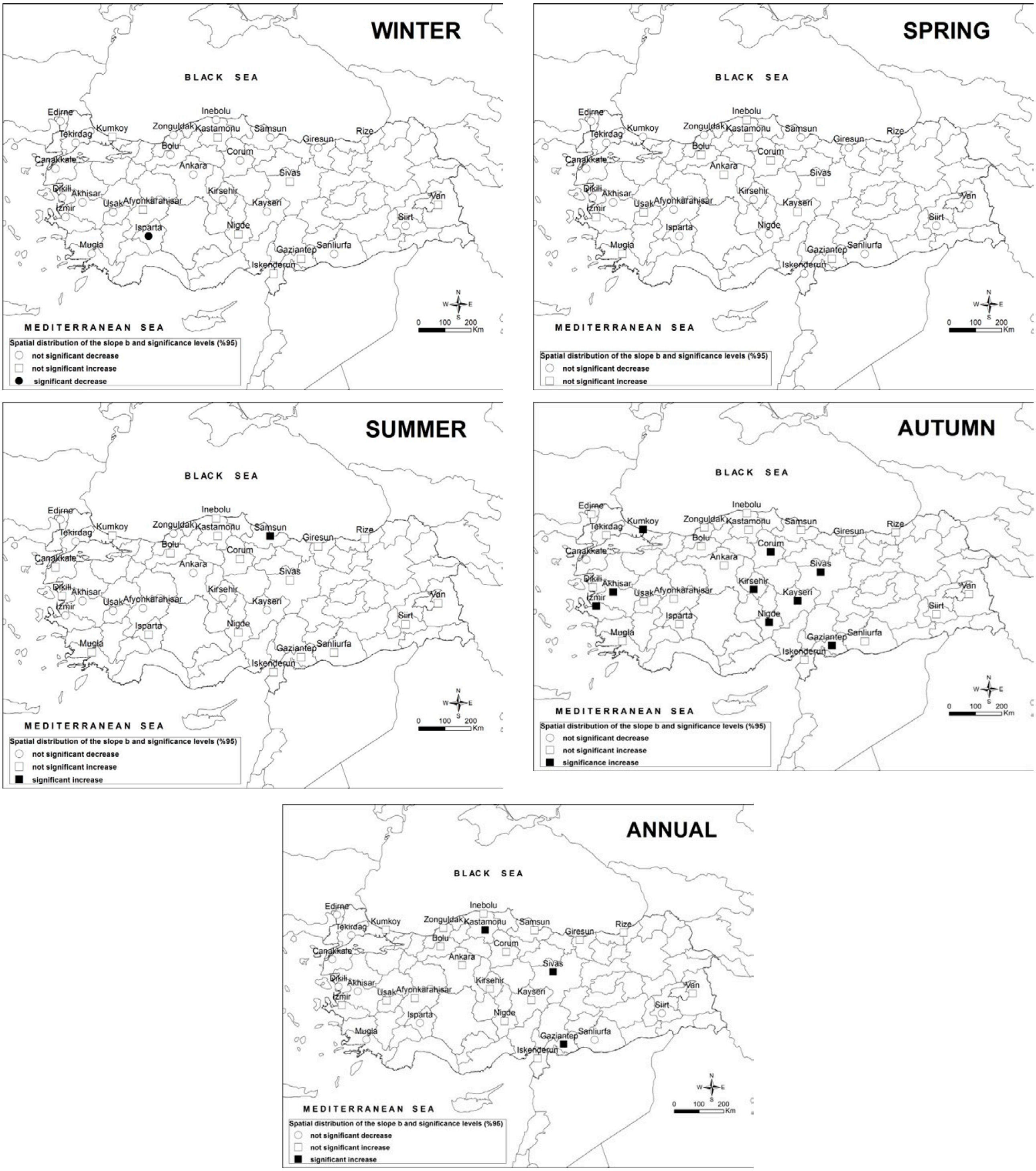

Fig. 3. Spatial distribution of the of the sign and statistical significance slope *b* values of the trend line for the seasonal and annual precipitation series (period 1955-2013). Squares indicate positive values and circles denote negative slope values. The filled symbols indicate a 95% confidence level.

on Turkey, respectively, which is consistent with the results of other studies (Feidas et al., 2007; Türkeş and Erlat, 2003; 2005; López-Moreno et al., 2011; Cullen et al., 2002) who found that the NAO extends into the Middle East and Turkey. Autumn and spring precipitation is weakly linked with the regional oscillation modes of EMP and MC.

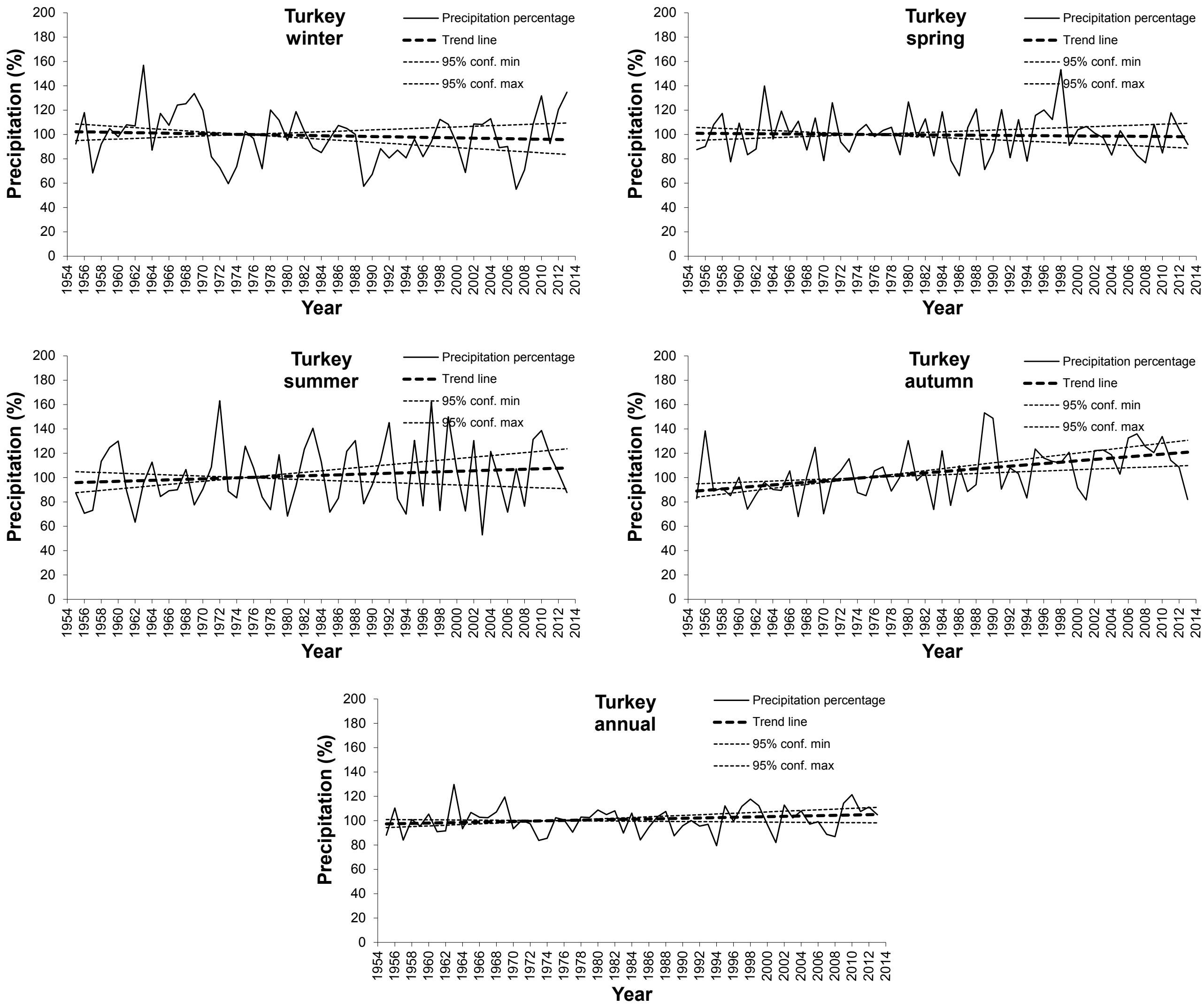

Fig. 4. Seasonal and annual precipitation averaged over Turkey, trend line and its lower and upper limits at the 95% confidence level (1955 – 2013). Precipitation observations are expressed as percentages of the normal for the 1961–1990 period.

The relationship between precipitation variability over Turkey and circulation indices (NAOI and MCI) can be physically explained as follows. In winters, positive (negative) values of the NAOI result from a strong (weak) meridional surface pressure gradient inducing northely (easterly) airflow that forces cold and dry (warm and wet) continental (maritime) air into the Mediterranean region.

Positive (negative) MCI values in winters are induced by a centre of strong positive (negative) sea level pressure anomalies over north-eastern Atlantic and the western Mediterranean combined with a center of negative (positive) surface pressure anomalies covering the eastern and south-eastern Mediterranean. These coupled pressure patterns build a strong meridional pressure gradient which brings cold and dry (warm and humid) northeasterly (southwesterly) airflow over the Mediterranean basin (Feidas 2017).

Precipitation trends may be explained by the temporal changes of the large-scale and regional scale atmospheric circulation patterns, mainly for autumn and winter. In particular, autumn precipitation in Turkey was found to be driven mainly by the Mediterranean Circulation (MC) atmospheric teleconnection. The trend analysis showed a statistically significant decreasing trend for the autumn MCI, which is in agreement with the corresponding rising trend in autumn precipitation over Turkey. This shift from positive to negative values of the MCI indicates a weakening of the meridional surface

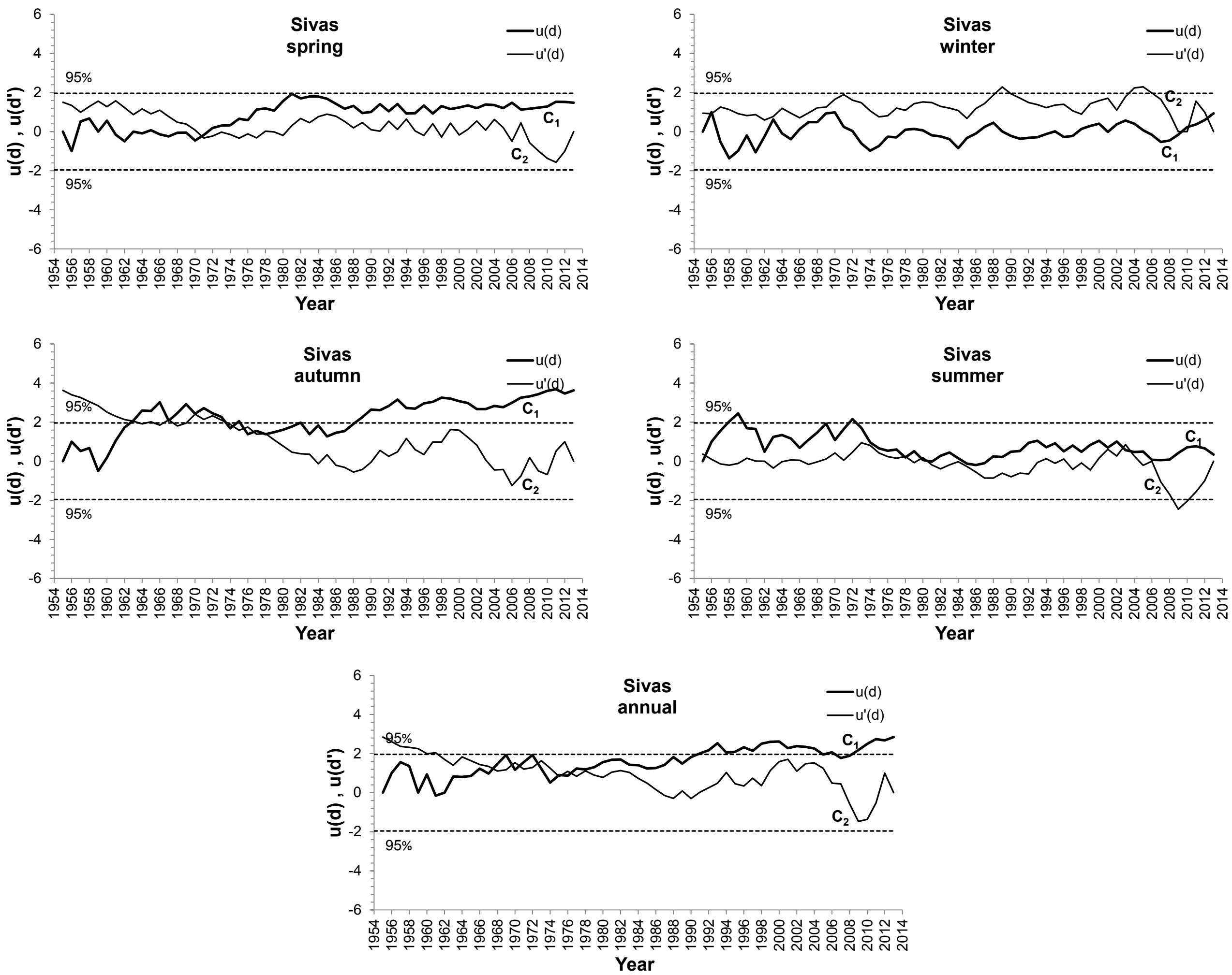

Fig. 5. Plot of the series of the Mann-Kendall statistics $u(d_i)$ (curve C_1) and $u'(d_i)$ (curve C_2), for seasonal and annual precipitation at the station of Sivas.

pressure gradient in autumn inducing easterly airflow that forces warm and wet maritime air into the Turkey from the Mediterranean region.

In winter, however, the NAO plays a crucial role in precipitation variability in Turkey as the centers of action of the NAO shift to the south. The observed slight, but not statistically significant, decreasing winter precipitation trend in Turkey is linked mainly to a rising trend in the hemispheric circulation modes of NAO which induces significantly cooler and drier conditions in Turkey.

Application of the Mann-Kendall rank statistics on the time series of the circulation indices NAOI and MCI indicated an upward trend in NAOI starting in 1971 and a downward trend in MCI initiating in 1984. These results match quite well with the starting years of changes in the winter and autumn precipitation time series, respectively.

The previous findings support the assumption that the Mediterranean Circulation and the North Atlantic Oscillation in pressure patterns can be considered a climatic forcing factor for Turkey.

4. CONCLUSIONS

Trends of seasonal and annual precipitation in Turkey were analyzed for the period 1955–2013, using two statistical tests. The trend analysis revealed the presence of variations and trends in Turkey. The link between precipitation variability in Turkey and atmospheric circulation patterns was also investigated using five atmospheric circulation indices.

On an individual station level, a distinct increasing trend ranging from 8.6%/decade to 14.7%/decade for the

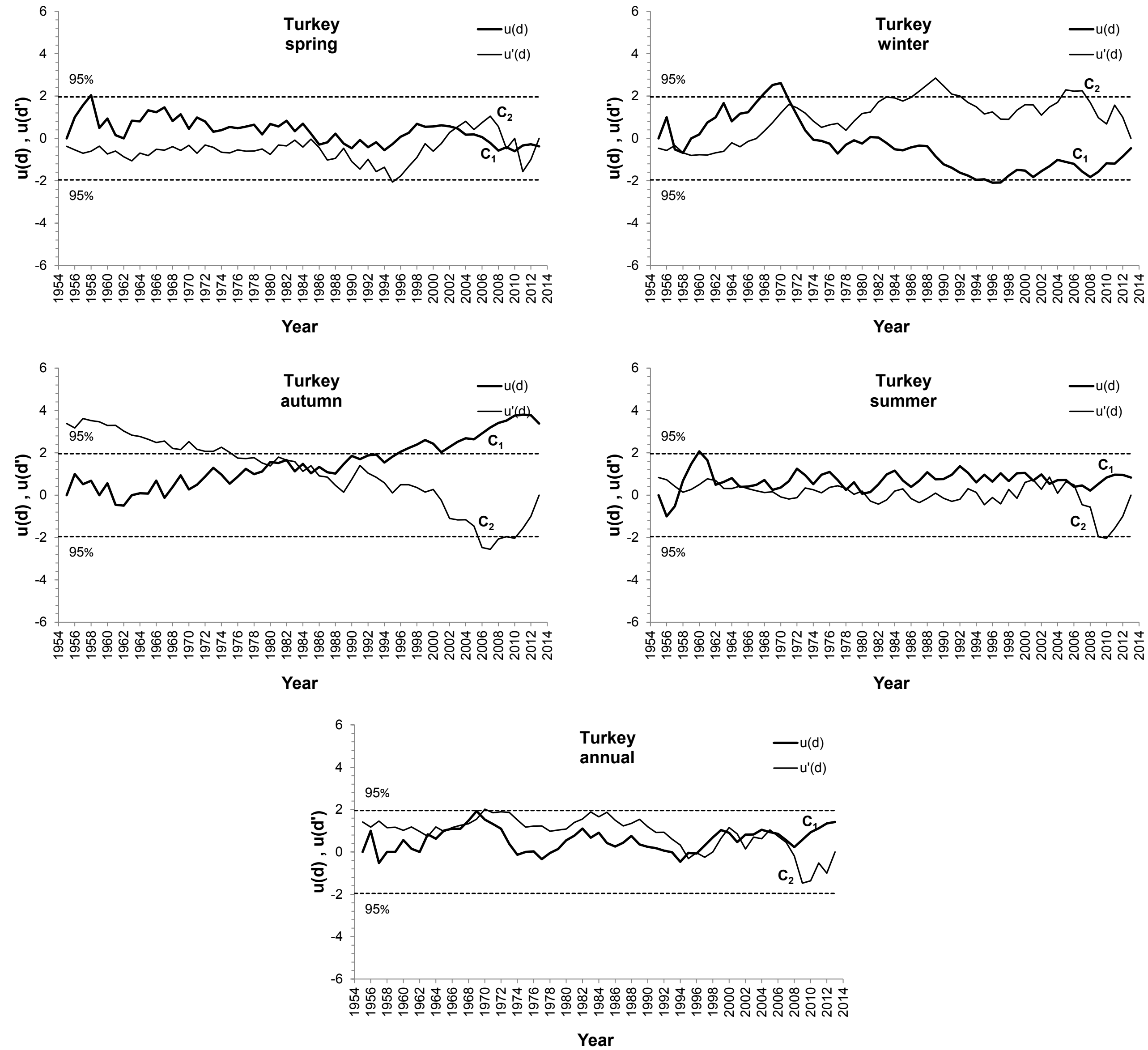

Fig. 6. Same as Figure 5 but for seasonal and annual precipitation averaged over Turkey.

whole period 1955-2013 is evident only in autumn precipitation series, which, however, is statistically significant only in a few stations (9 out of the 29 stations) located mainly in central Anatolia. Half of the 29 stations showed an upward trend starting from early 1960s to early 1980s. Although only one significant downward trend was detected in winter series for the whole period 1955-2013, the investigation of the initiation years of a trend showed a downward trend starting during the period 1970–1980 in almost one third of the stations. Only three stations were found to have small but statistically significant (upward) trends in the annual time series in the range 3.8 – 4.9% but there is not any clear signal in the starting year of the trends.

At the national scale, only autumn precipitation exhibits a clear significant upward trend of 5.5%/decade for the entire period 1955-2013. No clear significant trend was detected in the other seasons. Based on the investigation of abrupt precipitation changes, Turkey shows a distinct significant upward trend in autumn precipitation starting in 1984, whereas winter presents a downward trend initiating in 1971, which, however, seems to start reversing after 1996.

From a climatic point of view, changes in precipitation trends are the result of respective changes in atmospheric

Tab. 4. The starting year of the upward or downward trend for seasonal and annual precipitation, for the period 1955–2013, based on the Mann-Kendall test.

Stations	Winter	Spring	Summer	Autumn	Annual
Iskenderun	*	1965-	1968+	1977+	*
Kumkoy	*	*	1965+	2001+ (2011-)	1968+
Mugla	1980-	*	1955+	1968+	*
Izmir	*	*	*	1975+	*
Dikili	1974-	*	*	*	1964-
Gaziantep	*	*	*	1980+	1962+
Sanliurfa	1983-	*	*	*	*
Siirt	*	*	*	1960+	*
Isparta	1977-	*	*	*	1972-
Afyonkarahisar	*	*	*	*	*
Usak	*	*	*	1970+	*
Akhisar	1970-	*	*	1975+	*
Nigde	*	*	*	1997+	*
Kayseri	*	*	*	1961+	*
Ankara	*	*	*	*	*
Kirsehir	1978-	*	*	1968+	*
Corum	*	*	*	1964+	1960+
Sivas	*	*	*	1963+	1968+
Van	*	*	*	*	*
Canakkale	1971-	*	*	*	1963-
Edirne	1971-	*	*	*	1961-
Tekirdag	1963+ (1971-)	*	*	*	1957-
Bolu	*	*	*	1975+	*
Kastamonu	*	*	*	1968+	1962+
Zonguldak	1965-	*	*	1983+	*
Inebolu	*	*	*	*	*
Samsun	1960-	*	1989+	*	*
Giresun	*	*	*	*	*
Rize	*	*	*	1995+	*
Turkey	1971-	*	*	1984+	*

* No abrupt change found at the 95% level of confidence
\+ Increasing trend
\- Decreasing trend
( ) Year of a not statistically significant new abrupt change in a trend.

circulation. For example, the upward trend in autumn precipitation starting in 1984 and the downward trend in winter precipitation initiating in 1971, match quite well with the starting years of changes in the MCI and NAOI time series, respectively.

Analysis of the five circulation indices points out the strong link of precipitation regime in Turkey with variations in atmospheric circulation patterns. Precipitation variability in Turkey may be the result of variability of some coupled atmospheric circulation patterns (mainly the NAO and MC). More precisely, NAOI is the most suitable circulation index for explaining annual precipitation variability in Turkey. In addition, the MCI captures a large proportion of the precipitation variability in summer. Autumn and spring precipitation have a weak relationship with the regional oscillation modes of EMP and MC.

Tab. 5. Correlation coefficients of circulation indices with seasonal and annual precipitation in Turkey (95% level of confidence is indicated with boldface characters).

	Winter	Spring	Summer	Autumn	Annual
NAOI	**-0.45**	-0.18	-0.04	-0.09	-0.22
MOI	-0.24	0.06	-0.05	**-0.30**	-0.21
MCI	0.16	-0.01	**-0.47**	**-0.37**	-0.24
EMPI	**0.32**	**0.38**	0.10	-0.06	0.00
NCPI	**-0.39**	0.22	0.16	-0.08	-0.14

The link between precipitation variability in Turkey and atmospheric circulation patterns can also account for the observed precipitation trends over Turkey. In particular, the significant rising trend in autumn precipitation can be explained by the respective decreasing trend in the autumn MCI. The negative values of the MCI enhanced frequency of the northwest or northeast continental, dry and cold mid-tropospheric airflow advected from northern Europe leads to a lack of precipitation over Turkey.

This enhanced frequency of negative MCI values in autumn indicates a weakening of the meridional surface pressure gradient that induces an increased frequency of easterly maritime, warm and wet airflow advected from the Mediterranean Sea into the Turkey leading to an increase of precipitation over Turkey.

The observed slight but not statistically significant downward winter precipitation trend in Turkey is linked mainly to a rising trend in the hemispheric circulation modes of NAO. The enhanced frequency of positive NAOI values results in significantly cooler and drier conditions in Turkey as the increased frequency of northerly airflow brings continental, cold and dry air into the eastern Mediterranean region.

The findings of this study is in agreement with previous studies on the precipitation trends in the region (Türkeş and Erlat 2003; Türkeş et al., 2007; Feidas et al., 2007; Karabulut et al., 2008; Karabulut and Cosun 2009; Türkeş et al., 2009; Philandras et al., 2011). The important role of NAO and MCI in the precipitation regime of Greece and Turkey during winter has been also pointed out in the studies of Feidas et al., (2007) and Türkeş and Erlat (2003).

One major difference of our findings to previous studies covering similar periods (Toros, 2012; Efe et al., 2015; Sensoy et al., 2013) is that no statistically significant trend

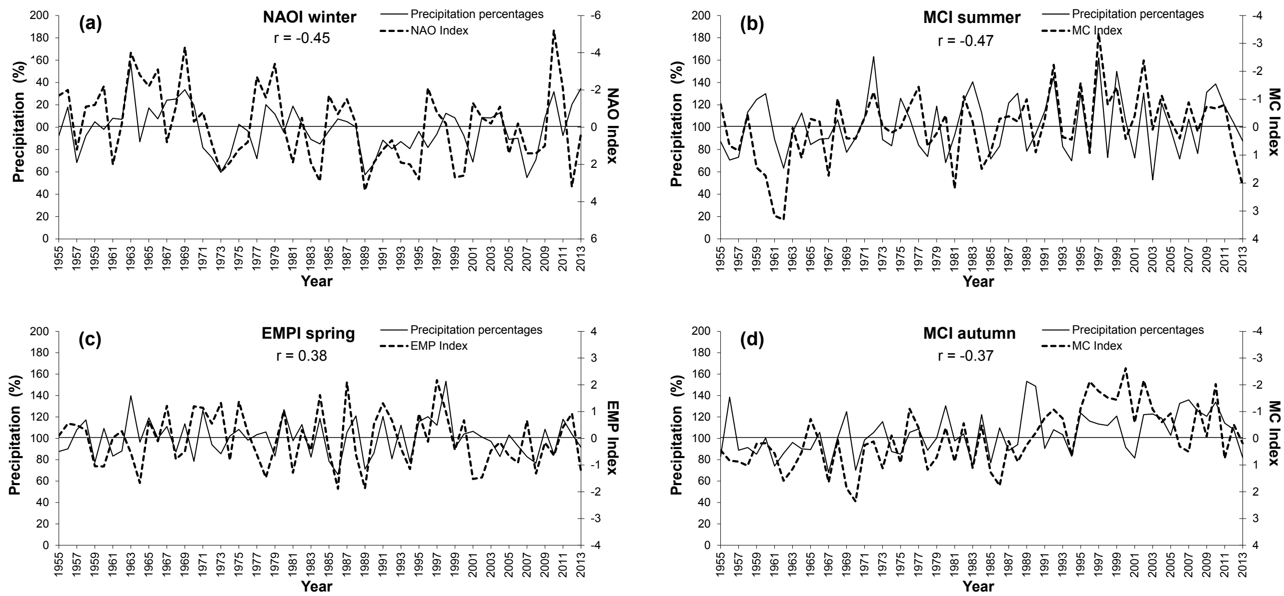

Fig. 7. Plots of the variability of seasonal precipitation in Turkey and seasonal circulation indices presenting the best correlation.

was found in our study in the annual and winter precipitation over Turkey for the examined period 1955-2013. In our study, only 3 out of the 29 stations were found to present a significant increasing trend in annual precipitation. It should be pointed out, however, that trend analysis results depend strongly on the time period of the time series and the statistical test used to detect the trend and its significance. Moreover, trends found in the study of Efe et al. (2015), were assessed and categorized differently. Another difference with these studies is that no significant correlation has been found between the annual precipitation and any of the atmospheric circulation indices in our study.

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