The links between the categorized Southern Oscillation indicators and precipitation patterns over Turkey

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Abstract. Previous global and regional studies have indicated teleconnections between the extreme phases of the Southern Oscillation (SO) and Turkey's hydrometeorological variables; however, they failed to suggest a strong correlation structure. In this study, the categorized Southern Oscillation Index (SOI) and Multivariate ENSO Index (MEI) series were used to examine the far reaching effects of the SO on Turkey's precipitation patterns. To represent neutral, moderate and extreme phases, SO indicators were subjectively categorized into five subgroups according to their empirical distributions. The correlation between the categorized SO indicators and Turkish precipitation series was computed from lag-0 to lag-4 using Spearman's *rho*. Significance of the calculated correlations was tested at the 0.01 level for the station based analysis and at the 0.05 level for the regional analysis. For some categories, precipitation was found to be correlated with the SO indicators at some stations mainly located in western Turkey. Regional analyses of precipitation revealed a clear and strong correlation structure with the categorized SO indicators over large portions of Turkey. This is an important fact that has not been emphasized by the pervious studies. Moreover it was shown that significant correlations were obtained not only for the extreme phases (namely, El Nino and La Nina), but also for the neutral and moderate phases of the SO.

1. Introduction

Because of the important influences of the Southern Oscillation (SO) on global climatic conditions, the extreme phases of the SO (namely, El Nino and La Nina conditions) and their influences on climate and water resources have always been an attractive topic for researchers. Global scale studies such as Bradley et al. (1987), Ropelewski and Halpert (1987, 1989), Kiladis and Diaz (1989) revealed notable teleconnections between precipitation and both El Nino and La Nina phases of the SO in some regions of the globe. In addition many regional climatic studies that mostly concentrated on the Pacific Rim regions (e.g., Redmond and Koch, 1991; Kahya and Dracup, 1993; Dracup and Kahya, 1994; Chiew et al., 1998; Eltahir, 1996) revealed noticeable link-

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ages between the El Nino/La Nina conditions and surface hydrometeorological variables.

The global scale study by Ropelewski and Halpert (1989) showed that eastern Mediterranean covering southern part of Turkey was a candidate area suggesting a notable El Nino-precipitation relation. Kiladis and Diaz (1989) indicated wetter than normal conditions during autumn and winter seasons of El Nino event year and drier than normal conditions during spring of following year at eastern Turkey with limited data coverage. Among the others, Karaca et al. (2000) observed noticeably increased precipitation in Turkey during the El Nino event of 1982-1983. However none of these studies concluded the existence of El Nino and La Nina effects on Turkish climatology in terms of sign, timing, magnitude, and geographic extent of the signal. The exceptions are the studies of Kahya and Karabörk (2001) and Karabörk and Kahya (2003) who documented the El Nino and La Nina effects on streamflow and precipitation patterns of Turkey.

Kahya and Karabörk (2001) revealed that there are two core regions with positive streamflow anomalies during April-October and April-November seasons of the El Nino event years in western and eastern Turkey, respectively. They also showed that time consistent dry La Nina signals on Turkish streamflow are only evident in eastern Turkey from May of the event year to February of the following year. For precipitation, Karabörk and Kahya (2003) stated that time consistent positive precipitation anomalies associated with El Nino events are evident in western and eastern Turkey during April-July and February-June seasons of the event years, respectively. They also showed that negative precipitation anomalies associated with La Nina events are detectable only in eastern Turkey during April-October seasons of the event years. As a summary, Turkish major hydrometeorological variables experience wetter conditions in association with El Nino events and dryer conditions in association with La Nina events. Using the same empirical methodology with the two former studies, Karabörk et al. (2005) analyzed the teleconnections between the extreme phases of the SO and temperature patterns of Turkey. They noted a cold signal season (from October of the event year to January of the following year) in western Turkey detected in monthly minimum temperatures associated with El Nino events.

In addition to the empirical analysis methodology, Kahya and Karabörk (2001), Karabörk and Kahya (2003) and Karabörk et al. (2005) calculated correlation coefficients between the hydrometeorological variables of Turkey and the SOI to obtain extra confirmations for the detected El Nino and La Nina signals. Although some significant correlations were found for a few stations, the correlation structure, in general, was poor in their studies. The results of some other studies, such as Cullen and DeManocal (2000), claimed that no clear correlation exists between the Turkey's hydrometeorological variables and SO indicators.

Jin et al. (2005) emphasize the importance of evaluating various methods to reveal influence of the SO in middle to high latitudes since there is limited and, sometimes, unsatisfactory evidence of SO influence for these regions. They detected significant correlations between the SOI and precipitation in Japan and Korea, using a simple method in which SOI data were categorized into five groups according to their magnitudes. In the present study, following the study of Jin et al. (2005), it is assumed that a simple categorization of SO indicators might be a good approach for eliminating the potential complexities of Turkey's hydrometeorology in relation to SO and provide better insights to atmospheric dynamics. It is hypothesized that the sign of the correlation between the SO indicators and Turkish precipitations may change depending on the SO phases; or, the influences of different phases may appear at different lags. These factors can cause the correlation coefficients appear insignificant as reported by a number of studies focused on the SO influence on Turkey's hydrometeorology. The objective of the present study is to reveal hidden patterns of SO influences on Turkey in the light of the teleconnections between the "categorized" SO indicators and Turkish precipitation.

2. Data and Methods

2.1. Precipitation data

We used high quality monthly precipitation totals (mm) from 88 stations (recorded by the Turkish Meteorological Office, DMİ). The distribution of precipitation gauging stations is almost uniform over Turkey. All of the precipitation records cover a 52-year period between 1951 and 2002.

2.2. Southern Oscillation indicators

To represent the state of the SO in the Pacific Ocean, the Southern Oscillation Index (SOI) series and Multivariate ENSO Index (MEI) series were employed. The SOI represents the state of the atmosphere in equatorial Pacific and is calculated using the sea level atmospheric pressures between Tahiti, Society Islands and Darwin, Australia. In this study, the SOI series was obtained through the web site of Australian Bureau of Meteorology. This center uses Troup's method in calculation of the SOI.

The MEI is obtained from the first unrotated principal component of six different atmospheric-oceanic variables over the equatorial Pacific. These variables are: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. It is obvious that the MEI includes more information than the SOI and stands to be a better indicator for representing the state of the SO. Therefore the SOI and standardized bimonthly MEI values were used in the analysis. Regularly updated standardized bimonthly values of the MEI starting from December 1949/January 1950 are available at the web pages of Climate Diagnostic Center. Unlike the SOI, the positive values of the MEI indicate the El Nino-like conditions.

2.3. Correlation analysis

Nonparametric Spearman's *rho* correlation coefficient was employed in this study. Nonparametric techniques have some advantages over parametric techniques such as being distribution free of the data and more robust for outliers. Since the SOI and MEI series are standardized series (they have a monthly mean of "0" and a monthly standard deviation of "1" over base periods), prior to the correlation analyses, monthly precipitation values were decided to be standardized by subtracting monthly means and dividing by monthly standard deviations. All correlations were calculated based on three-month averaged seasons. In this case, for a year, four seasonal averages were calculated for precipitation values and for the SOI values such as Season 1 including January, February and March; Season 2 including April, May, and June, and so forth. Similarly, four seasonal averages of the MEI within any year were calculated using bimonthly MEI values.

Seasonal mean values of the SOI and MEI series were categorized into five groups. The categorization of the SOI into five groups was also made by Jin et al. (2005), considering the magnitudes of the SOI such as SOI<-2; -2<SOI<-1; etc. However, in the present study, the categorization of the SOI and MEI was performed based on their empirical distributions during period 1951-2002, rather than pre-selected threshold levels. For the categorization of the SOI, ranks were assigned to the seasonal averages. In this instance, the rank of the lowest seasonal value is 1; whereas the rank of the highest one is 208 (total number of the seasonal averages is 52×4=208). Then, SOI values were assigned to the categories depending on their ranks: Category 1 consists of the seasonal values whose ranks range from 1 to 41; while Category 5 consists of values whose ranks are between 168 and 208. For the Category 2, Category 3 and Category 4 SOI values, rank intervals were defined as 42-83, 84-125, and 126-167, respectively. It is visible that except for Category 1 and Category 5, the number of the SOI values included in each category is 42. The categorization of the MEI is similar to that of the SOI except the fact that a rank of "1" is given to the highest value, and a rank of "2" to the next highest value, etc. For the MEI, rank of the lowest values is 208. To clarify the categorization procedure, Category 1 (Category 5) SOI and MEI series might be considered as the El Nino-like (La Nina-like) conditions whereas Category 3 series might be considered as neutral phase of the SO. Similarly, Category 2 and Category 4 series are representatives of the moderate phases of the SO for analysis periods.

The analysis approach is to correlate the categorized SO indicators (SOI and MEI) with precipitation starting lag-0 to lag-4. To explain the calculation of lag correlations, suppose that, any SOI category is composed of the SOI values of *Season 2 of 1955, Season 4 of 1956,..., Season 3 of 2000*. For this category, lag-0 correlations are calculated between the SOI values of *Season 2 of 1955, Season 4 of 1956,..., Season 3 of 2000* and concurrent precipitation values. For the calculation of lag-"*k*" correlations, precipitation values are lagged *k* seasons with respect to the SOI. For instance, for the assumed SOI category above, lag-2 correlations are calculated between the SOI values of *Season 2 of 1955, Season 4 of 1956,..., Season 3 of 2000* and precipitation values of *Season 4 of 1955, Season 2 of 1957,..., Season 1 of 2001.* The significances of the calculated correlation coefficients were tested at 0.01 and 0.05 levels for station based and regional based analyses by two tailed *t* test, respectively.

3. Results and Discussions

3.1. Station based analysis

The analysis of Category 1 SOI and precipitation series showed significant negative correlations at lag-3 (5 stations) and lag-4 (12 stations). Detected lag-4 correlations (depicted in Figure 1) provide an extra confirmation to the results of Karabörk and Kahya (2003) who indicated a wet El Nino signal season in western Turkey. The locations marked in Figure 1 also confirm the indications of Karabörk et al. (2007) since they demonstrated that relative effects of the El Nino events on Turkey's precipitations lessen from west to east. For the Category 1 the MEI-precipitation teleconnection, the correlation structure was weak compared to the SOI-precipitation teleconnection. The stations Bayburt and Bingöl (eastern continental Turkey) have significant positive correlations with the MEI at lag-2 whereas only the station Dikili (western coast of Turkey) has been found to be positively correlated with the MEI at lag-4.

When the Category 2 index series were used, the stations Florya, Göztepe, Kireçburnu and Kocaeli (located around İstanbul, northwestern Turkey) were found to be negatively correlated with the MEI at lag-2. Apart from these lag-2 correlations with the MEI, five (three) stations had significant positive correlations with the MEI at lag-0 (at lag-1). The locations of these positive lag 0 and lag 1 correlations correspond to southern half of Turkey. For the Category 2 SOI series, some significant positive correlations were detected at lag-2 (2 stations), lag-3 (4 stations) and lag-4 (1 station). Except for the station İnebolu (located on Black Sea coast) all of the significant SOI correlations were detected in eastern Turkey.

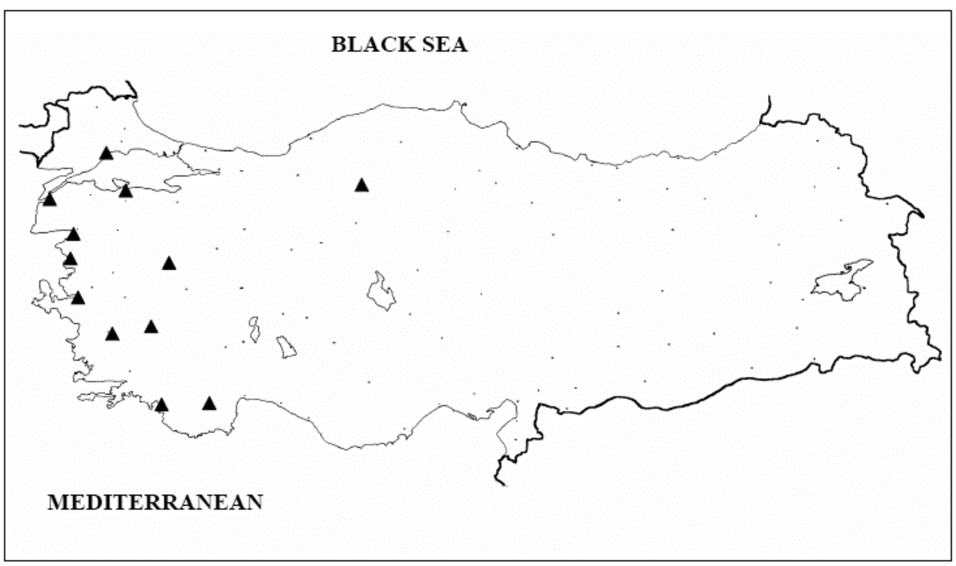

Figure 1. Locations of the precipitation stations (denoted by solid triangles) that have negative lag-4 correlations in association with the Category 1 SOI.

For the Category 3 series, the correlation structure between the MEI and precipitation seemed to be stronger than that of the SOI-precipitation relation. Thirteen out of 88 stations, located in western Turkey as seen in Figure 2, were found to be positively correlated with the MEI at lag-4. In addition to these correlations, the stations Bolu, İnebolu, and Sinop (the Black Sea coast) showed negative significant correlations with the MEI at lag-2. For the SOI-precipitation relation, the stations Edirne, Kırklareli and Lüleburgaz (far northwestern Turkey) showed significant positive correlations at lag-2.

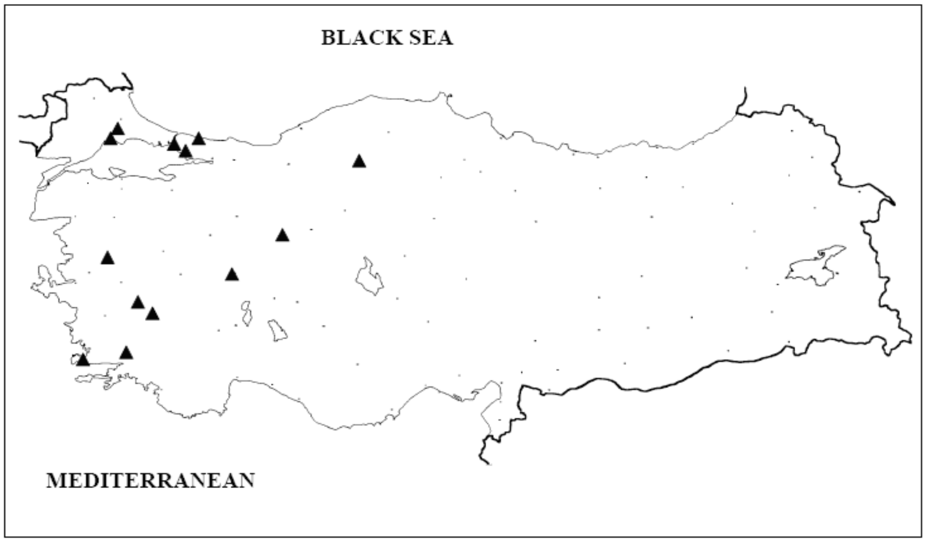

Figure 2. Locations of the precipitation stations that have positive lag-4 correlations in association with the Category 3 MEI.

For the Category 4 SOI and MEI series, no significant correlation was detected over Turkey. In the analysis of Category 5 series, the significant correlations were found in 8 out of 88 stations at lag-4 with the MEI. The sign of the correlation is positive and locations of the stations were shown in Figure 3.

The detected significant correlations, depicted in Figure 1 and Figure 2, seemed to be in agreement with the results of Karabork et al. (2005), who detected *Pearson's r* correlations between the uncategorized SOI and precipitation. However, except for a few stations, detected correlations for western Turkey (and in general across Turkey) were at 0.10 and 0.05 significance levels. As far as significance level of 0.01 is considered, the present study provides more satisfactory results than the pertinent studies in order to suggest a SO influence on western Turkey.

3.2. Regional Analysis

When dealing with large scale atmospheric oscillation patterns such as Southern Oscillation, the use of spatially averaged time series is a reasonable approach for detecting the teleconnections between the large scale oscillations and climatic variables. Most of the previous studies (Kahya and Dracup, 1993; Kahya and Karabörk, 2001; Karabörk and Kahya; 2003; etc.) had used regional time series in concluding the influences of the extreme phases of the SO in candidate regions. Therefore, correlations were calculated between the categorized SO indicators and regional precipitation time series. Regional series were established by averaging standardized individual precipitation series.

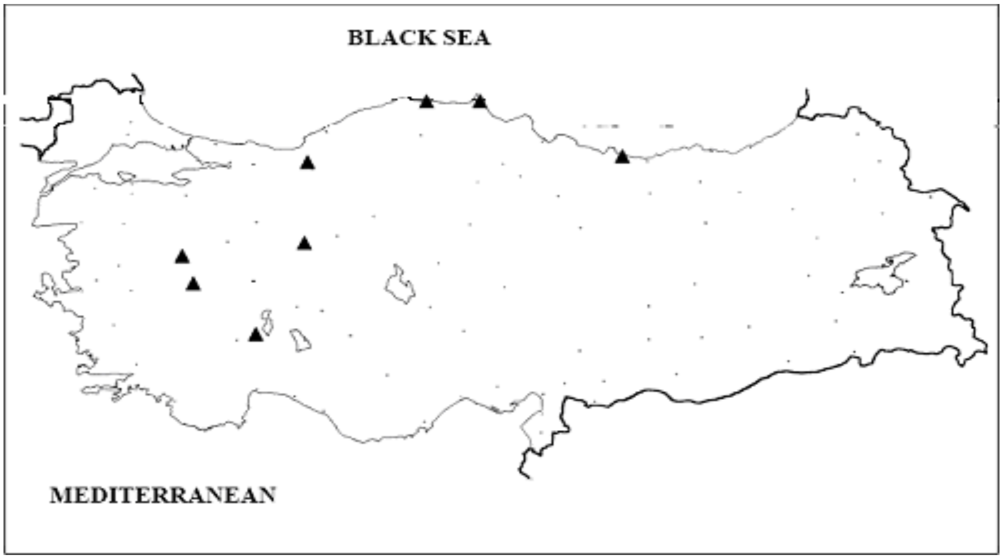

Figure 3. Locations of the precipitation stations that have positive lag-4 correlations in association with the Category 5 MEI.

The averaging procedures were performed on the basis of homogeneous climate zones of Turkey defined by Ünal et al. (2003). Figure 4 shows the homogenous climate zones of Turkey.

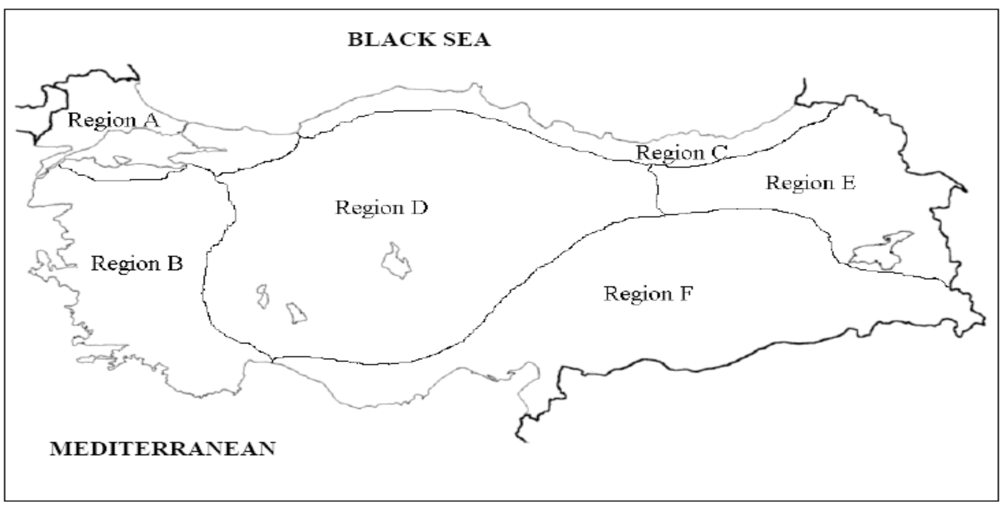

Figure 4. Homogeneous climate regions of Turkey. The borders of the regions were adopted from Ünal et al. (2003)

The correlation structure for all categories between the categorized SO indicators and regional precipitations is presented in Table 1. For the 0.05 significance level, the spatial coverage of the significant correlations noticeably increased. The results obtained for the Categories 2, 3 and 4 reveal the influences of moderate and neutral phases of the SO on Turkey's precipitation patterns that have not been implied by the previous studies. Table 1 also exhibits significant correlations between Category 1 SO indicators and Turkey's precipitations and provides extra confirmations to the results of Karabörk and

Kahya (2003) who showed the existence of El Nino signals in western and eastern parts of Turkey.

Table 1. Significant correlations between the categorized SO indicators and regional precipitation patterns of Turkey.

Category	Region	SOI					MEI				
		Lag					Lag				
		0	1	2	3	4	0	1	2	3	4
1	A			-							
	B					--					
	D				-	-			+		
	E				-					+	
2	A								-		
	C				+				--		
	E			++							-
	F					+	++	+			
3	A										++
	B										++
	D										+
4	B		+								
	D									-	
	E								-		
5	A				-						
	C										++
	D				-						+

- : negative correlation at the 0.05 significance level
-- : negative correlation at the 0.01 significance level
+ : positive correlation at the 0.05 significance level
++: positive correlation at the 0.01 significance level

However, the results obtained for Category 1 do not provide an extra confirmation pertaining to the timing of the El Nino signal within an El Nino year, since the Category 1 SOI and MEI series were set from all seasons (season 1, season 2, etc.) in the period 1951-2002. These correlations also seem to be in agreement with the results of Fraedrich and Müller (1992). They argued that the trajectory of the Atlantic depressions tends to shift southward during El Nino phases resulting in wetter conditions over southern Europe. In contrast, the storm tracks tend to move northward during La Nina phases resulting in dry conditions over southern Europe and Mediterranean basin. The GCM simulations of Mathieu et al. (2004) have shown that El Nino events favor wetter conditions in Southern Europe. In fact, results of Fraedrich and Müller (1992) associated with El Nino and La Nina phases typically describe the influences of the negative and positive phases of the North Atlantic Oscillation (NAO) over Europe and Mediterranean basin. Therefore, a link between the extreme phases of the SO and NAO may be hypothesized to bring a physical explanation to findings of Table 1 as discussed in detail by Karabörk et al. (2005) who argued that El Nino and La Nina signals could be transmitted from tropical Atlantic to mid-latitudes of Atlantic Ocean. It is worth noting that many researchers have recently pointed out the remote impacts of equatorial Pacific on the tropical North Atlantic (i.e., Enfield and Mayer, 1997; Giannini et al. 2000, 2001) and, in particular, Marshall et al. (2001) presented a physical mechanism for the effect of tropical Atlantic on the NAO through Hadley circulation. This physical mechanism is also explanatory for the detected positive significant correlations between the Category 5 MEI values (implying La Nina conditions) and Turkish precipitations shown in Table 1. Nevertheless, further studies are needed to explain the detected SO-precipitation relations in Category 2, Category 3 and Category 4.

4. Conclusions

In this study, the correlation structure between the categorized SO indicators and Turkey's precipitation patterns were analyzed. As a general evaluation, regional and station based analyses revealed significant correlations between the phases of the SO and Turkish precipitations. It should be stressed that significant correlations have been determined not only for the extreme phases of the SO but also for the moderate and the neutral phases that have been considered seriously for Turkey for the first time. In this study, categorization of the SO indicators into five groups created an opportunity to detect stronger correlation structures than those of the previous studies regarding the SO influences over Turkey's hydrometeorology. In the correlation analyses, the sign of correlation was noted to vary depending on the SO phases considered. The results given in this study provide noticeable contribution for demonstrating far reaching effects of the SO on Turkey and eastern Mediterranean, and indicate a need for further studies focusing not only on the extreme phases but also other phases of the SO to understand global atmospheric dynamics.

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