Comparison of rotated and unrotated principal components of Turkish streamflow

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Abstract. We recently defined systematic modes of spatial and temporal variation in a 372-month record of streamflow using the principal components analysis (PCA). The unrotated and orthogonally rotated (varimax) components were previously calculated from a matrix of monthly streamflow records of 78 stations in Turkey for the period 1964-1994. As a result, the basic anomaly patterns by the unrotated components and the hydrologically homogeneous regions by the rotated components were successfully documented for Turkish streamflow data. As a complementary study, we herein intended to compare the two different sets of principal components (i.e., unrotated and rotated) to test their overall performance with regard to the following five criteria. First, we compared the two sets in terms of temporal variations in the monthly PC scores by plotting the time series of the first five components. A tendency to wet or dry season within the study period was noted for each component's plot. Second, we compared the first unrotated and rotated PCs of annual streamflow to the aggregate precipitation series (precipitation records of 96 stations with a period 1964-1994 were all averaged to obtain the aggregate series). Although correlation was a little better for the unrotated PC, their performance were almost the same. Third, we applied the same procedure as in the second case except for the aggregate streamflow series. The unrotated PC showed better harmony with the aggregate streamflow series than its counterpart. Fourth, we compared the first unrotated and rotated PCs of annual streamflow in terms of how well they are correlated with NAO index. Fifth, we compared the fifth unrotated and rotated PCs of annual streamflow in terms of how well they are correlated with SO index. The performance of the two types of PC for the last two comparisons seemed to be similar, but the unrotated resulted in enhanced relation with the atmospheric circulation indices.

1. Introduction

The systematic modes of spatial and temporal variation in streamflow conditions over a region are conveniently displayed by means of streamflow

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anomaly maps. These maps basically show regions of above-normal, normal, or below-normal streamflow conditions. The nature of the spatial pattern of streamflow variations might be brought to light inspecting sequences of these maps (Bartlein, 1982).

In our earlier recent studies, we have documented a quantitative characterization of the long-term covariance structure in monthly and/or annual flows from a nationwide data set of Turkey streamflow records (Kahya and Kalaycı, 2002; Kahya and Kalaycı, 2006) using principal components analysis (PCA). Following this work, we used PCA with varimax rotation mainly for the purpose of identifying hydrologically homogeneous regions (Kahya et al., 2007). We were able to define streamflow regions in coherence to previously defined climate region. Both studies were a first for Turkey.

In this study, we were concerned about a rough overall comparison of the both cases: rotated and unrotated solutions. For comparing criteria we used some approaches that were applied by one of our studies above. Herein we put all these approaches in one and applied to the both unrotated and rotated PCs.

2. Data

The mean annual streamflow values of 78 gauging stations are used in this study. The records span from October of 1964 to September of 1994 and obtained through Electrical Power Resources Survey and Development Administration (EİE). Stations are distributed with more or less uniformly across Turkey. This streamflow data set was previously used by Karabörk and Kahya (2001). The selection criteria of the stations included were: (i) homogeneous distribution as much as possible; (ii) records without gap; (iii) no upstream interference. Further details for the homogeneity condition of the streamflow records can be found in Karabörk and Kahya (2001).

3. Methodology

Principal components analysis (PCA) is a technique to examine the spatial or temporal variability of geophysical fields (Preisendorfer, 1988; Walsh and Mostek, 1980). The PCA has been successfully used in hydrologic sciences to explain the fundamental nature of streamflow (Bartlein, 1982; Lins, 1985). It results in a new set of variables that are linear combinations or transformations of the original variables. The time-dependent coefficients of these fields in the linear combination are called principal components (PC). The dominant modes of spatial variability in our nationwide streamflow data set are represented in terms of PCs of the 78x372 observation matrix. It is worth noting that each observation consists of the seasonally standardized flow values after transforming to logarithms at the first step. In our case, the PCA is to condense 372 streamflow anomaly maps into a smaller number of patterns, explaining most of the variance of the anomaly field.

4. Results and Conclusions

Summary of Significant PCs for the Unrotated and Rotated Analysis

In this section we tabulated the main results of our earlier studies to compare both type of solutions (Table 1). This table includes only significant components based on "Rule N" (Lins, 1985). There is a noticeable difference between PC1s in terms of the percentage of total variance explained. It is again notable that starting PC2 all the remaining PCs had a higher percentage for the rotated solution than the unrotated solution. This means that except PC1 all the other PCs in the rotated solution had a relatively more consequential representation of streamflow anomaly fields. However the impact of PC1 in an overall evaluation should not be overlooked.

Table 1. Comparison of the percentages of variance explained by the first twelve PCs for the unrotated and rotated solutions.

Principal component	Unrotated	Rotated (varimax)	Principal component	Unrotated	Rotated (varimax)
1	38.166	20.605	7	2.323	3.741
2	13.751	14.601	8	1.978	2.910
3	7.115	9.707	9	1.794	2.603
4	4.346	8.424	10	1.702	2.568
5	3.415	5.698	11	1.336	2.112
6	2.550	5.280	12	1.305	1.531
			Σ	**79.780**	**79.780**

In our earlier studies, we have determined basic anomaly patterns in a map-fashion for the both unrotated and orthogonally rotated cases. Rather than map comparison, we herein are concerned with comparing the both solutions from other various standpoints that were previously applied only to one solution.

Component Scores

The PC scores indicate the relative importance of each PC for each of the 372 months in the record. Time series plots of the scores for the first five orthogonally rotated (unrotated) PCs are depicted in Figure 1 (Figure 2). Herein we only present a detailed evaluation only for the first component of rotated and unrotated PC. The monthly scores for the rotated PC1 exhibit roughly a broad quasi-sinusoidal variation. This pattern indicates that during the period 1964-1994 two cyclic parts of above mean streamflow occurred on a nationwide scale. The time series of scores of this first component exhibits a downward trend during the periods 1970-1976 and 1984-1994. The relevant contour map (not shown here) showed that near average streamflow conditions characterized most parts of the country between 1972 and 1977; very low streamflow conditions prevailed after 1988 as a persisted drought. The variation of this component clearly reflects the occurrence of widespread drought events in early 1970s and 1990s and wet conditions during 1960s and the late 1970s (Türkeş, 1996). In the case of unrotated PC1 (Figure 2), since the anomaly score fluctuations in the time series seem quite alike those for the rotated PC1, the above comments are valid.

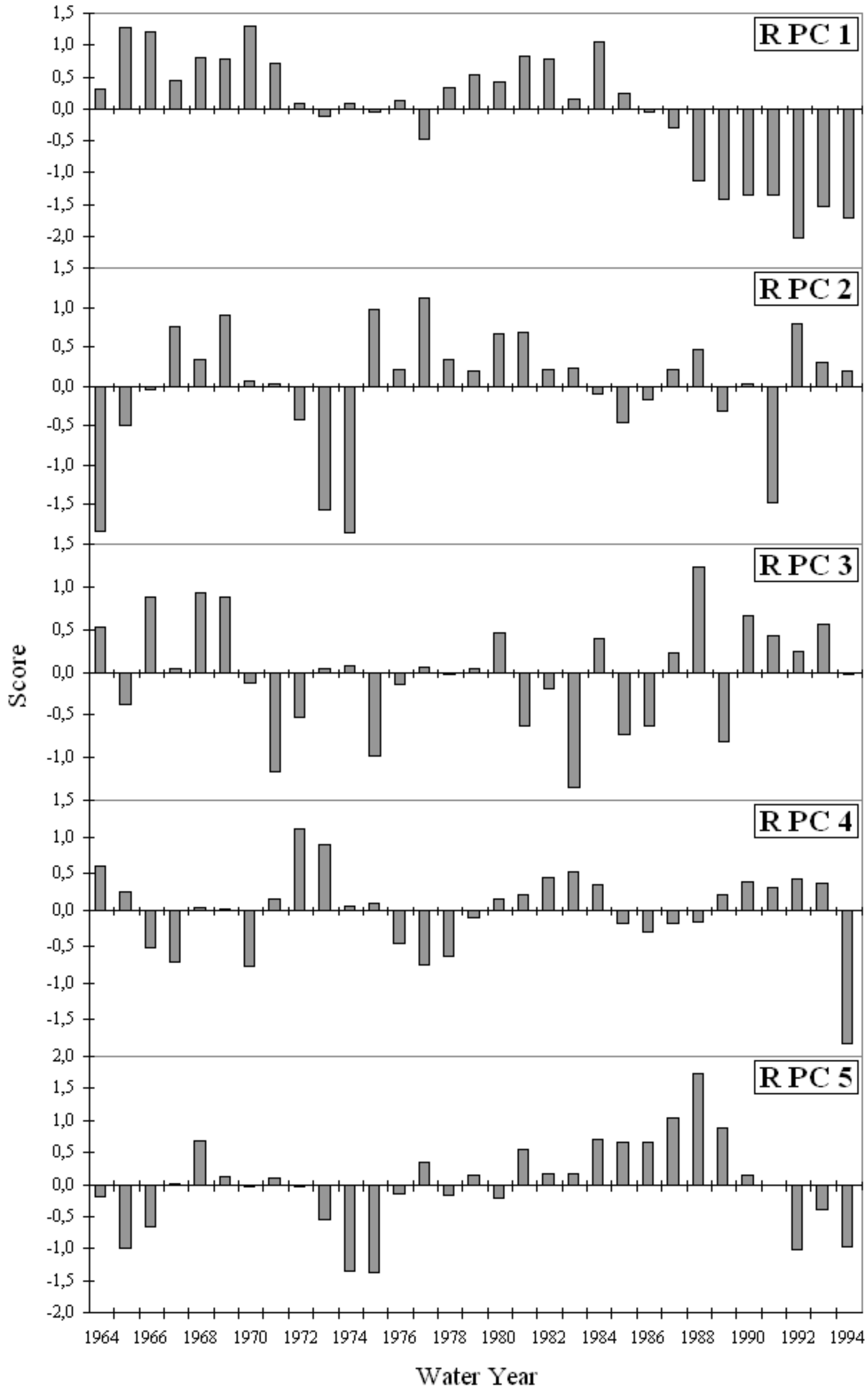

Figure 1. Temporal variations of orthogonally rotated PCs of monthly streamflow.

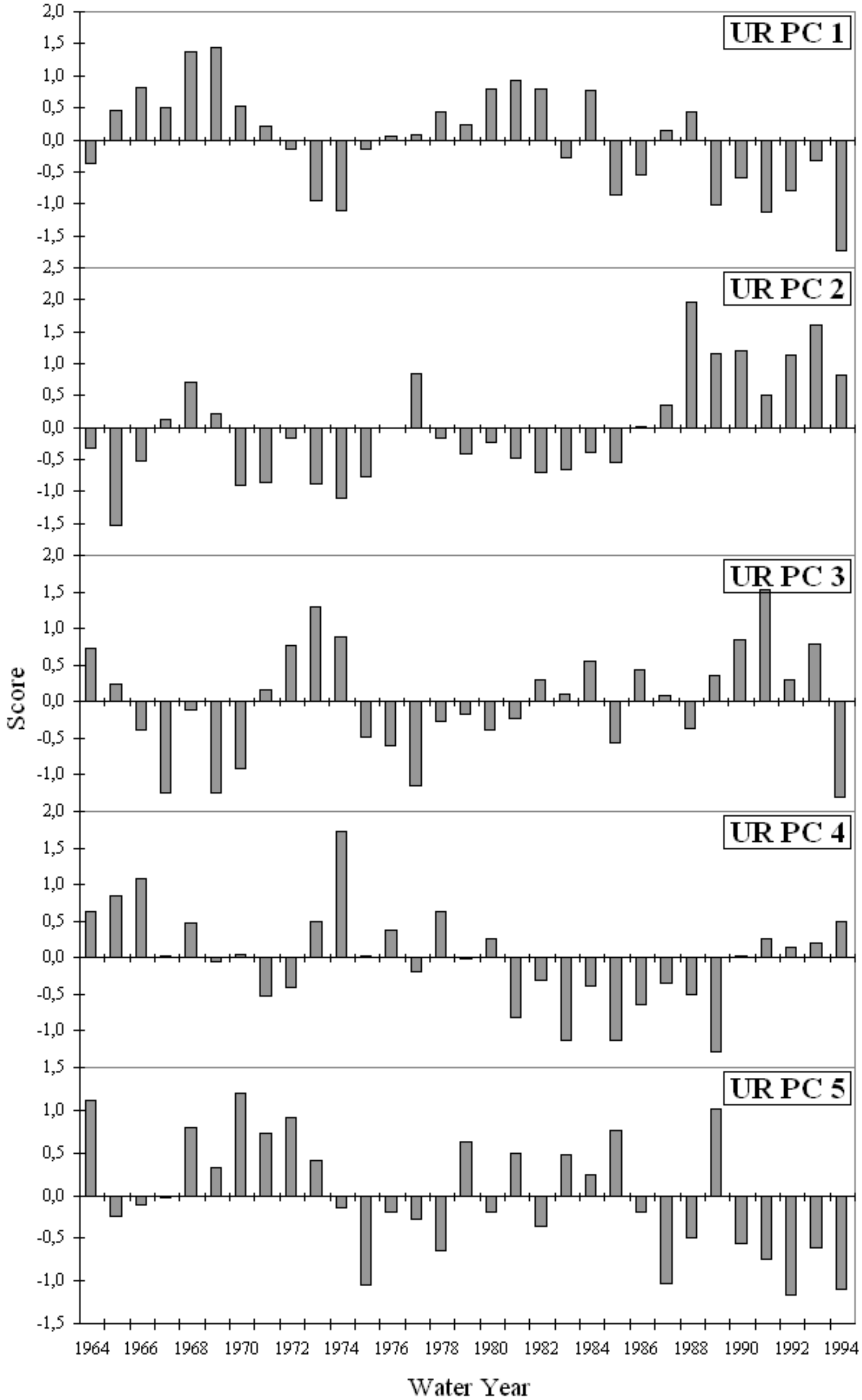

Figure 2. Temporal variations of orthogonally unrotated PCs of monthly streamflow.

The time series of scores of the rotated PC2 exhibits an upward trend during the period 1964-1968; and also a downward trend during the period 1970-

1974. These two features can also be seen in that of the unrotated PC2 with relatively low magnitudes. The variation of the rotated PC2 clearly reveals two major wet periods during the periods 1962-1969 and 1975-1981, and major two dry periods during the periods 1970-1974 and 1982-1993 with the exception of 2-year wet break in 1987 and 1988 (Türkeş, 1996). After 1980, the unrotated PC2 have fluctuations differed from those of its counterpart with more strong anomaly runs. Similar comparison can be made for the other components.

For the remaining 3 components of the two cases, the percentage of similarity obviously decreases, implying that rotation made a noticeable difference in the solution. The trend type behaviors of streamflow in Turkey were extensively discussed by Kahya and Kalaycı (2004).

Relation between the index mean annual precipitation and the rotated and unrotated PC1s:

The time series of scores of the first rotated and unrotated streamflow PCs were plotted to compare with the index annual mean precipitation for the study period (Figure 3). The index annual mean precipitation was obtained by averaging all annual precipitation records at 96 gauging stations, which were complied by Turkish State Meteorological Service, for the interval 1964-1994. By the visual inspection of Figure 3, a close association between three variables is fairly evident. We computed cross correlation coefficients to quantify the linear relation between two variables.

The simultaneous correlation between the unrotated streamflow PC1 scores and the index precipitation values was found as 0.596 which is statistically significant at the 99.9 % confidence level. Similarly, we calculated a value of 0.363 for the rotated streamflow PC1 scores, which is statistically significant at the 95 % confidence level. The unrotated PC1 is in stronger relation with the index mean precipitation than its counterpart. As precipitation is the major generating factor to streamflow it is thus natural to expect a high level of association between the two hydroclimatic variables. In this regard, the performance of the unrotated component is superior.

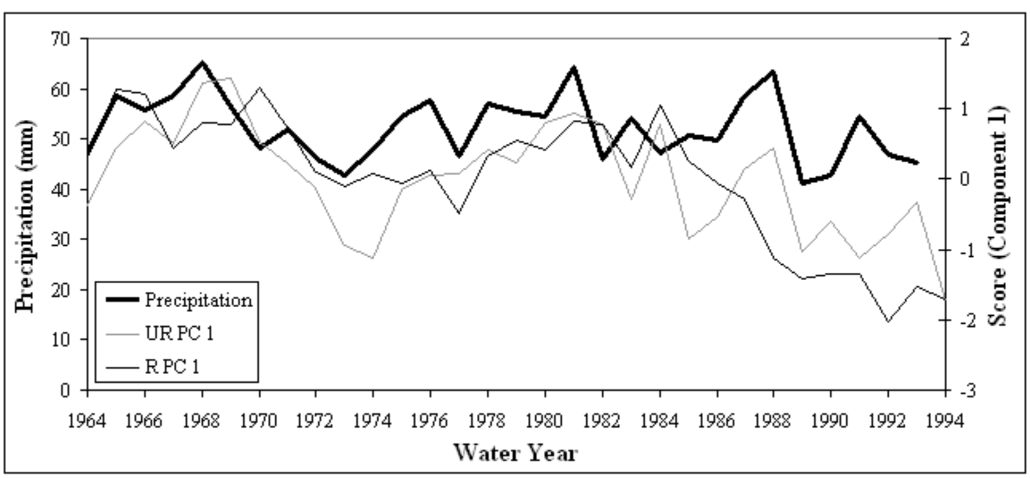

Figure 3. Annual variations of the first streamflow unrotated and rotated PC1s and the index annual mean precipitation.

Relation between the index mean annual streamflow and the rotated and unrotated PC1s:

Similar to the analysis in the preceding section, the time series of scores of the first rotated and unrotated streamflow PCs were now plotted to compare with the index annual mean streamflow for the study period (Figure 4). The index annual mean precipitation was formed by averaging all annual streamflow records at 78 gauging stations across Turkey for the interval 1964-1994.

Figure 4 shows highly related three time series as expected. The lag zero cross correlation between the unrotated streamflow PC1 scores and the index streamflow values appeared to be equal to 0.9566 which reflects almost a perfect relation. Similarly, we calculated a value of 0.5644, significant at the 99 % confidence level, for the rotated streamflow PC1 scores. This result is not surprising as the percentage of explained variance for the unrotated PC1 is higher than its counterpart (numerically 38.1% versus 20.6%). The difference in their corresponding PC1 maps also helps understand the numerical difference of the two correlations. Once again, the performance of the unrotated component is superior in this respect.

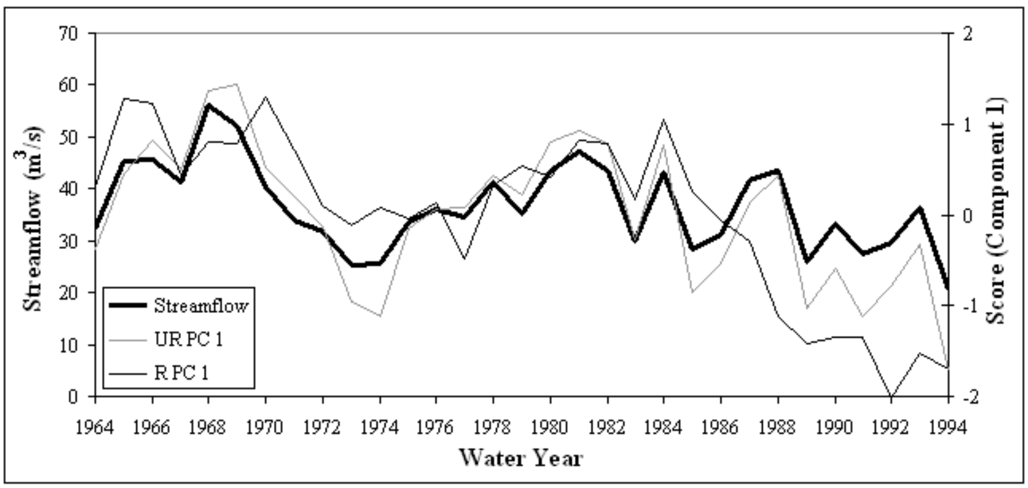

Figure 4. Annual variations of the first streamflow unrotated and rotated PC1s and the index annual mean streamflow.

Relation between the NAO index and the rotated and unrotated PC1s:

In this section, the relationships between the unrotated and rotated PC1s and the series of the NAO (supplied from Climatic Research Unit, UK) have been examined based on annual means. The plots of the three variables are given in the same diagram (Figure 5). The correlation value for the pairs of NAO and rotated PC1 was calculated as -0.4664. Similarly the correlation value for the pairs of NAO and unrotated PC1 was calculated as -0.4908. In this comparison, their performances are nearly same and the both PCs are said to be significantly negatively related to the NAO at the 99% level. Karabörk et al. (2006) discussed the NAO influences on streamflow variability in Turkey in detail.

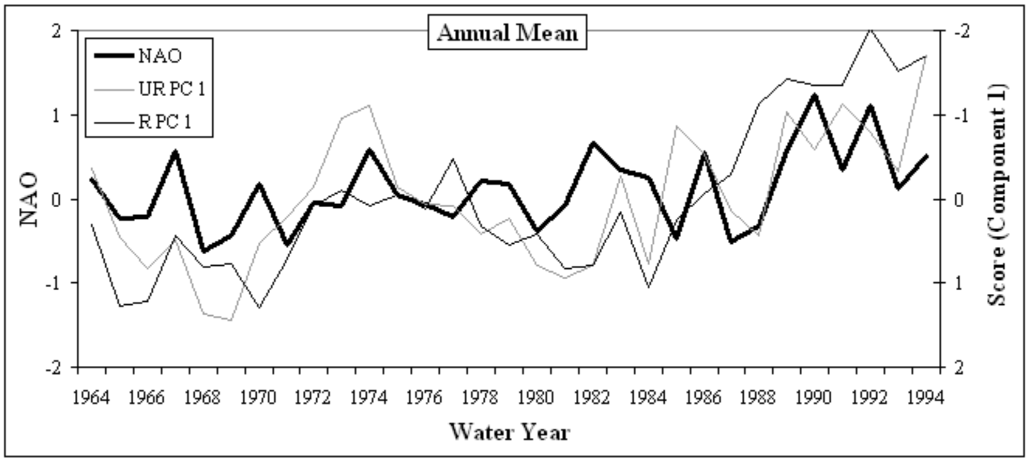

Figure 5. Annual variations of the first streamflow unrotated and rotated PC1s and the NAO index series.

Relation between the SOI index and the rotated and unrotated PC5s:
In this section, the relationships between the unrotated and rotated PC1s and the series of the SOI (supplied from Climate Prediction Centre, USA) have been examined based on annual means. Figure 6 depicts the three variables for the study period. We found a correlation value of 0.3943 at the 95 % significance level between the unrotated PC5 and the SOI whereas similar relation was found insignificant for the counterpart pairs. Therefore it might be speculated that the varimax rotation removed the occurrence of the SO signal in the PC5 variation mode. Kahya and Karabörk (2001) explained the SO extreme events signals on streamflow pattern in Turkey.

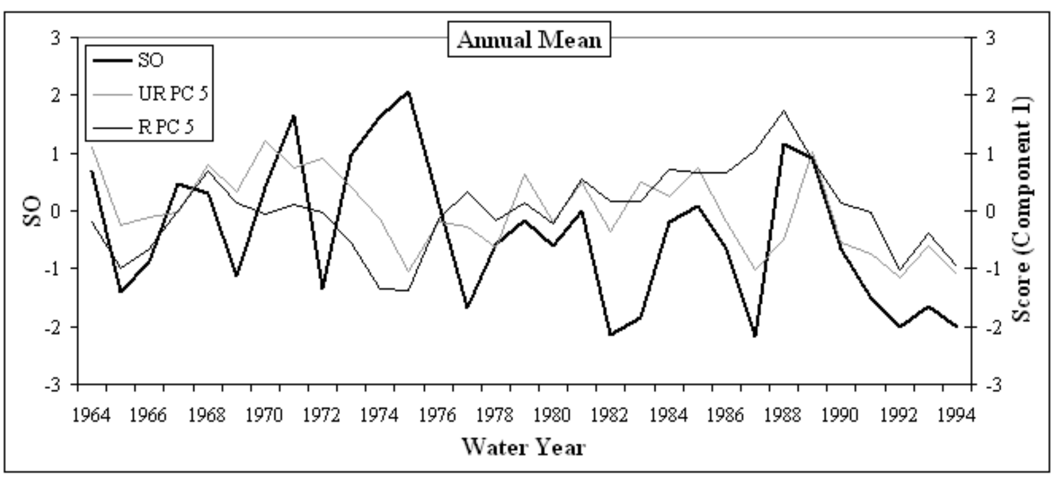

Figure 6. Annual variations of the first streamflow unrotated and rotated PC5s and the SOI index series.

In conclusion, the unrotated components seem more meaningful solutions than their counterparts in terms of representing the spatial modes of streamflow variability in Turkey and in terms of physically interpreting. However if it was aimed to identify homogeneous regions, the use of rotated solutions is recommended as the map evaluation was more appropriate (Kahya et al. 2007).

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