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APPLICATION OF CANONICAL ANALYSIS TO AIR TEMPERATURE AND PRECIPITATION REGIMES OVER GREECE

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SUMMARY

The goal of this study is to estimate the relation between air temperature and precipitation in Greece and, thereafter, to define the regions of the covariability of the two parameters. For that purpose, the air temperature and precipitation mean monthly data of 30 meteorological stations, for the period 1950-2000, are analyzed.

The first step is the application of Factor Analysis (FA) to each of the two variable groups of the seasonal air temperature and precipitation. The aim is to reduce the number of variables in each group and, more specific, to define the main significant factors for each parameter. The second step is the application of Canonical Correlation Analysis (CCA) to the factor scores of each parameter, derived by the use of PCA, so that the canonical pairs are extracted and the number of the pairs are equal to the minimum number of variables in either set.

In the process, the computed canonical scores are correlated to the respective original data, aiming to define regions of positive and negative correlations between the canonical roots of the air temperature and precipitation.

KEYWORDS: Canonical correlation analysis, Factor analysis, Air temperature, Precipitation, Greece.

INTRODUCTION

Greece covers the southern edge of Balkan Peninsula, being in the eastern basin of the Mediterranean Sea. The most important centers of atmospheric activity, which form the weather in Greece are: i) the anticyclone of Azores, ii) the seasonal Siberian anticyclone, iii) the moving anticyclones of Europe, iv) the moving anticyclones which are directed to the North Africa from the Atlantic Ocean, v) the depressions moving in a track along the Mediterranean Sea (either local or coming from the Atlantic Ocean) and vi) the Indian low.

As far as the cold period of the year (October-April) is concerned, the anticyclone of the Atlantic Ocean being in the area of Azores, expands easterly to the North Africa reaching Egypt, to the West Mediterranean Sea and to the West Europe. The Siberian anticyclone covers part of Russia and sometimes expands either to the Balkans or from the northwest Siberia to the Middle East, Asia Minor and East Mediterranean Sea. Regarding the depressions in the Mediterranean Sea, they are moving in determinant tracks having discriminative frequencies, [1, 2]. Generally, the depressions have the tension to move to the north, [3, 1] and there is the general remark that they move over plain surface or at low altitude, avoiding the mountainous obstacles. The moving anticyclones of Europe are characteristic of the cold and warm period of the year.

Especially during the warm period of the year (May-September) the anticyclones of the Azores are moving to higher latitudes and expanding towards east to Europe. Also, the Indian low expands towards the west to the East Mediterranean Sea and Asia Minor. It is clear from the context that during the cold period, because of the anticyclones in Europe and Siberia and low pressure in the Mediterranean Sea, the dominant wind blow in Greece is from the north, being occasionally interrupted as the wind blows from the south according to the passage of the depressions in the Mediterranean Sea and Europe. In the warm period, Greece is under the Etesians regime, which are winds of the north. As far as the precipitation distribution is concerned, Greece, as the whole of the Mediterranean Sea, is distinguishable in two periods: the wet and the dry period. The dry one coincides with the summer period [4].

The present study is to reveal the relation between air temperature and precipitation regimes over Greece and, in the process, explain the causes that are responsible for this relationship. Thereafter, the spatial distribution of the patterns for each statistically significant pair of air temperature and precipitation is presented for winter and summer period.

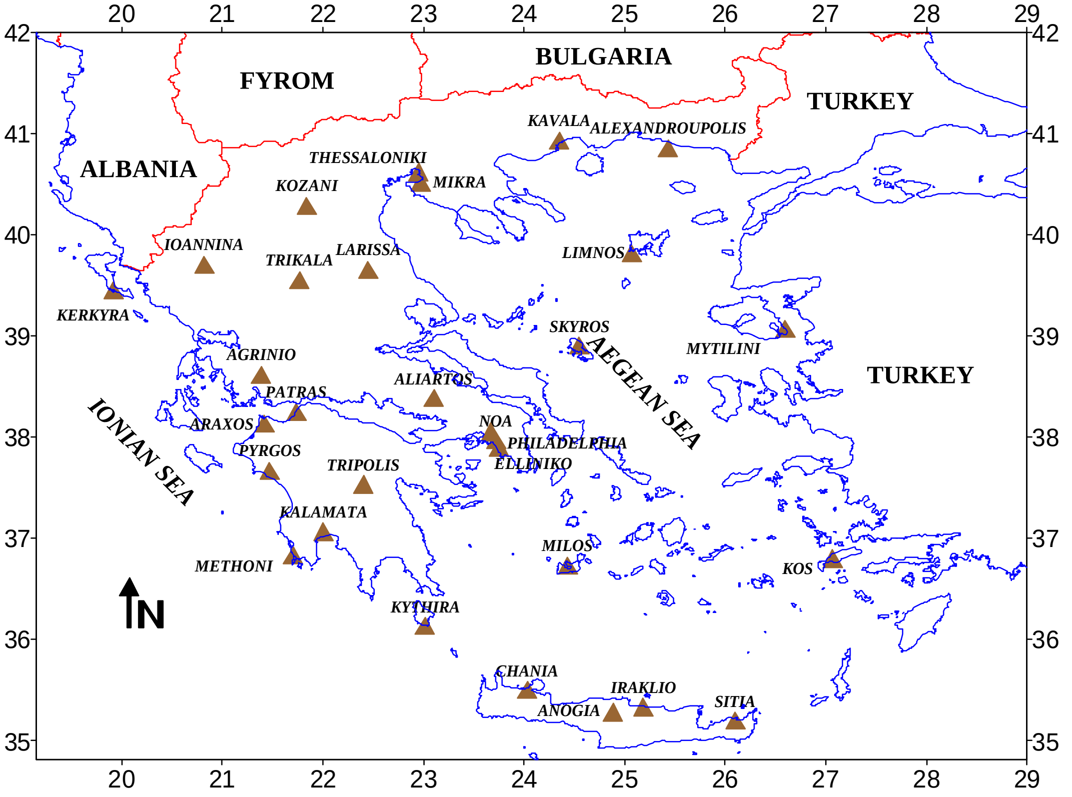

FIGURE 1 - Network of the meteorological stations.

DATA AND METHODS USED

The data used in the assessment of the relation examined between air temperature and precipitation in Greece consists of mean monthly data of air temperature and precipitation from 30 meteorological stations of the National Meteorological Service for the period 1950 – 2000. The network of the meteorological stations is plotted in Figure 1. The first step is to compute the seasonal data for air temperature and precipitation, which will be the initial variables for the analysis followed. The statistical methods used are the Factor Analysis (FA) and the Canonical Correlation Analysis (CCA). These methods are briefly discussed.

The main applications of FA are to reduce the number of variables and detect the structure in the relationships between variables, that is to classify variables. Therefore, FA is applied as a data reduction or structure detection method. The data should have a bivariate normal distribution for each pair of variables, and the observations should be independent. Thus, each of the p initial variables $X_1, X_2, \ldots, X_p$ can be expressed as a linear function of m $(m<p)$ uncorrelated factors: $X_i = a_{i1}F_1 + a_{i2}F_2 + \ldots + a_{im}F_m$, where $F_1, F_2, \ldots, F_m$ are the factors and $a_{i1}, a_{i2}, \ldots, a_{im}$ are the factor loadings which express the correlation between the factors and the initial variables. The values of each factor are called factor scores and they are presented in the standardized form, having zero mean and unit variance [5, 6]. The number m of the retained factors has to be decided, by using various rules (Eigen value ≥ 1, scree plot) and considering the physical interpretation of the results [7]. Another important point of the analysis is the rotation of the axes, which maximizes some factor loadings and minimizes some others and in that way a better separation among the initial variables is achieved. Varimax rotation is generally accepted as the most accurate orthogonal rotation, which maximizes the sum of the variances of the square factor loadings, keeping the factors uncorrelated [8].

CCA is searching for relation between two sets of variables $X_1, X_2, \ldots X_p$ and $Y_1, Y_2, \ldots, Y_q$. The first step of the method is to calculate the constants $a_{11}, a_{12}, \ldots, a_{1p}$ and $b_{11}, b_{12}, \ldots, b_{1q}$ in the linear combinations:

$$W_1 = a_{11}X_1 + a_{12}X_2 + \ldots + a_{1p}X_p,$$

$$V_1 = b_{11}Y_1 + b_{12}Y_2 + \ldots + b_{1q}Y_q$$

such that the correlation coefficient between W_1 and V_1, $C_1 = \mathrm{cor}(W_1, V_1)$, is at a maximum. W_1 and V_1 are called canonical variates and C_1 is called canonical correlation. The second step is to determine another set of canonical variates:

$$W_2 = a_{21}X_1 + a_{22}X_2 + \ldots + a_{2p}X_p,$$

$$V_2 = b_{21}Y_1 + b_{22}Y_2 + \ldots + b_{2q}Y_q$$

such that the correlation $C_2 = \mathrm{cor}(W_2, V_2)$ = maximum and W_2 and V_2 are uncorrelated to W_1 and V_1. It is clear that the two sets of canonical variates are uncorrelated. The analysis is continued up to the *m*th set of canonical variates, where m = min(*p*,*q*). So, *m* sets of canonical variates (W_1, V_1), (W_2, V_2), ... , (W_m, V_m), are determined in a way that: i) the corresponding canonical correlations C_1, C_2, ... , C_m are at a maximum and ii) $\mathrm{cor}(V_j, V_k)$ = $\mathrm{cor}(W_j, W_k)$ =$\mathrm{cor}(W_j, V_k) = 0$, j ¹ k [9, 10]. Finally, only the statistically significant pairs are used, as they are got by the application of various criteria [10].

In this work, FA (S-mode) [8] was applied for each seasonal initial matrix 30x51, (30 meteorological stations and 51 years) of air temperature and precipitation in order to reduce the number of the initial variables. Many researchers have followed this technique of reduction of the dimensionality of the initial data sets before the application of CCA [11, 12, 13]. In the process, CCA was applied on the two sets (air temperature and precipitation) of the factor scores time series derived, for the four seasons.

Finally, each of the resultant canonical variates was correlated to all the original time series of the respective parameter, so that an interpretation of the relation between air temperature and precipitation regime be achieved.

RESULTS AND DISCUSSION

The application of FA on winter air temperature and precipitation revealed that two and four factors, respectively, describe well the variability in Greece, explaining the 85% and 70% of the total variance of each parameter. Thereafter, CCA was applied to the two sets of factors scores in order to investigate the possible relationship between air temperature and precipitation. The result was two canonical pairs with statistically significant correlation at 95% confidence level (r = 0.68 and r = 0.52). In order to interpret the findings the correlation coefficient of the canonical variates with the respective original data was estimated. Hence, the two canonical pairs were plotted.

The first canonical pair (W1, V1) is presented in Figure 2 and the regions with correlation coefficient greater than 0.6 were shaded. It is obvious that when high air temperature appears almost all over the country, then high amount of precipitation falls at the west, north and east regions of Greece (Figure 2).

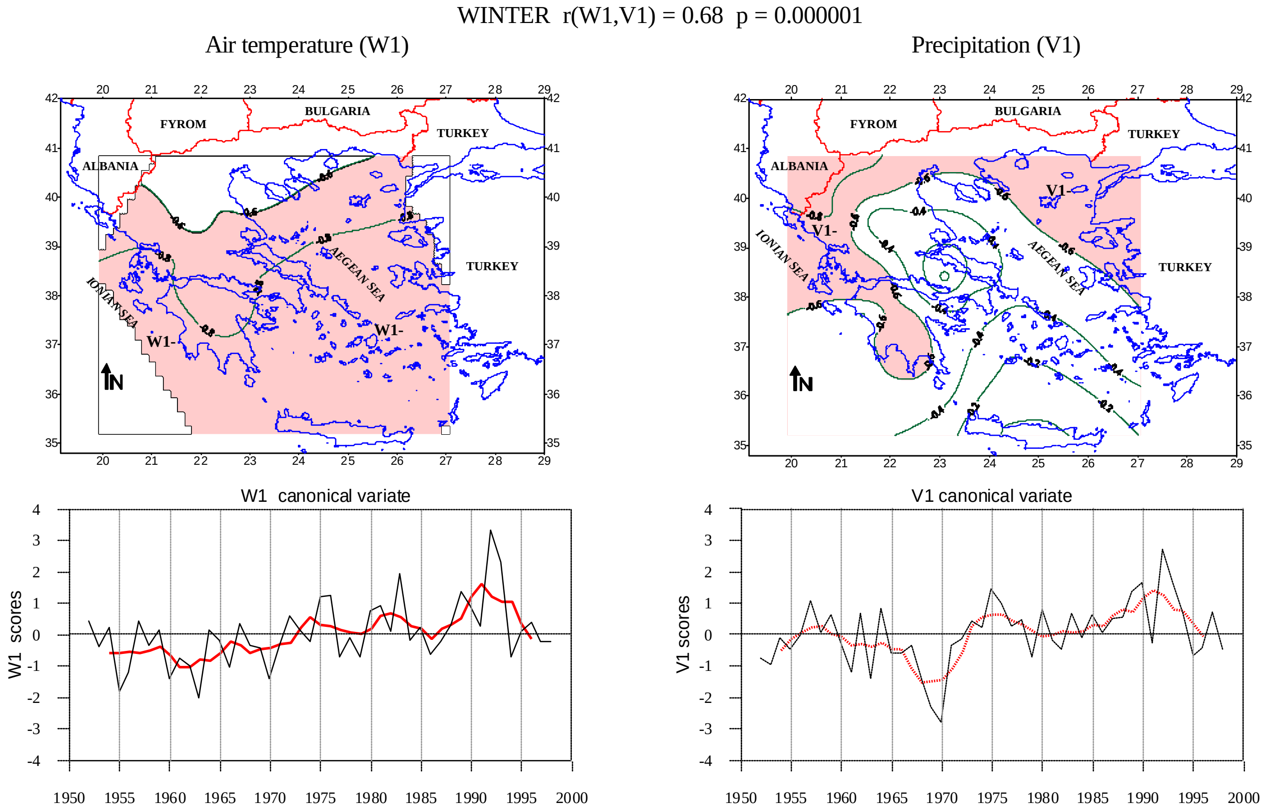

FIGURE 2 - The first canonical pattern and the time series of the canonical variates along with 5-year moving averages for Winter, (W1 for air temperature and V1 for precipitation).

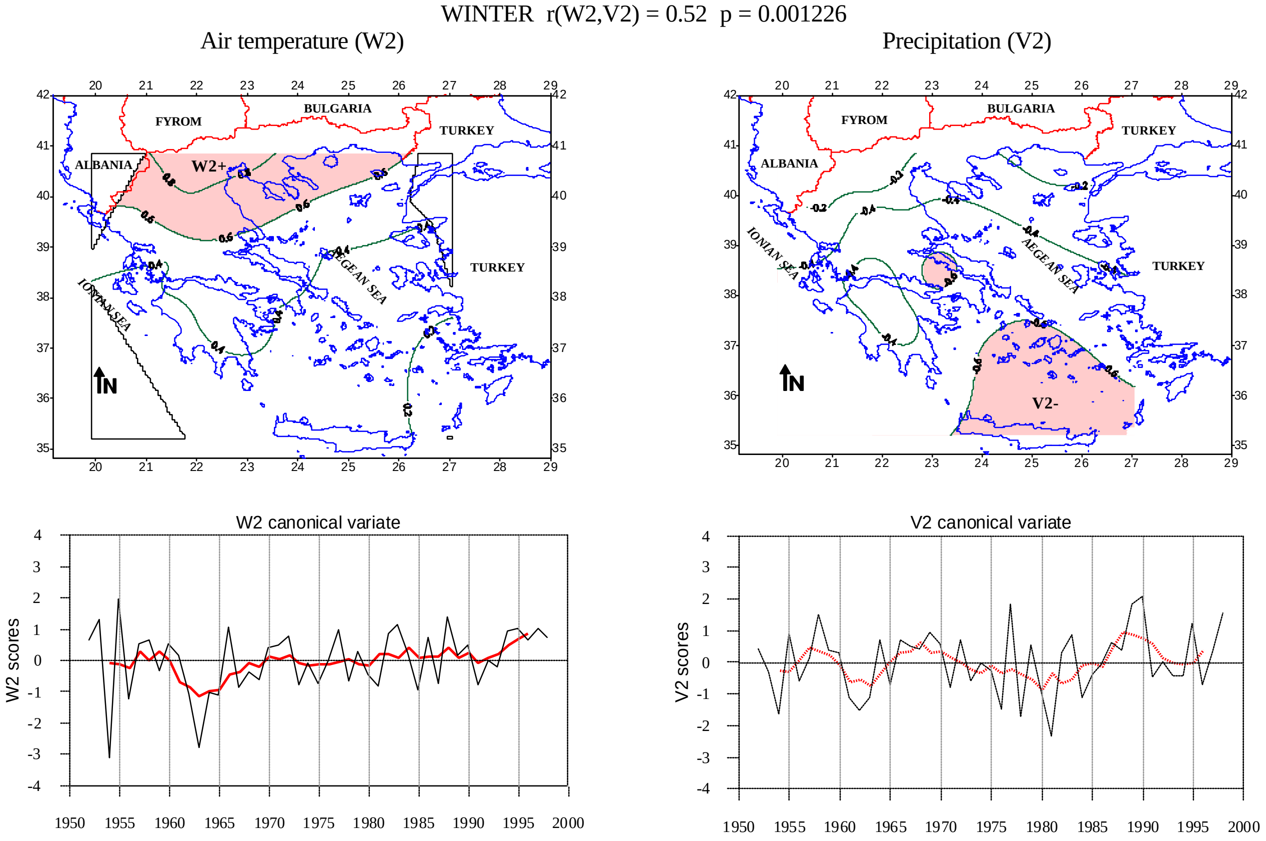

FIGURE 3 - As in Figure 2, but for the second canonical pattern.

This is due to the interactions of the south and more effective parts of the depressions, the tracks of which happen to be in regions between North Greece and North-East Europe [14]. The cold front of these depressions moving from west to east covers the whole country. The warm section consists of tropical continental (cT) air masses from North Africa, which are dry and warm, but in the process moving over the Mediterranean Sea, their comprehensiveness in water vapors is increasing. The warm fronts of these depressions are moving either from north-west to north-east or from west to east. Usually they are at the north of Greece or in rare cases at North Greece. The blow of south winds for a great period before the coming of the warm front, results in the cT air masses from North Africa cover large space of the Balkan Peninsula and hence the rise of air temperature is achieved.

The precipitation is of large intensity especially in West and North-West Greece, with the appearance of thunderstorms. It is important to pinpoint that these precipitations are mainly of the cold front or of the unstable air masses within the warm section of the depression, because the precipitations are apparent especially at the mountainous regions of the West Greece.

The second canonical pair (W2, V2) is presented in Figure 3, where the spatial distribution of the correlation coefficient shows a different pattern for the air temperature and precipitation regimes. As in Figure 2, the regions with correlation coefficient greater than 0.6 are shaded. The North Greece is under low temperatures, while high amount of precipitation appears at the South Aegean Sea. This is due to the depressions having tracks mostly south of Greece covering the country with their north section. These depressions are very deep and extensive and result in the weather of Southern Greece (Crete island, Central and South Aegean Sea) as other regions, depending on their intensity and expansion. The warm section of these depressions covers the south regions of Greece and consists of tropical continental (cT) air masses, while Northern Greece is under the influence of polar continental (cP) air masses, which reduces the air temperature. Hence, because of the cold fronts of the depressions, high amounts of precipitation fall in the Southern Greece, while the Northern Greece keeps low air temperatures.

It is important to remark that during the cold period of the year the frequency of the depressions moving in a track to the North or through Greece is greater than the one of the depressions moving to the South of Greece (9.2% and 1.2%, respectively) [14].

The pattern of the second canonical pair is also seen when an anticyclone, which is established over the Balkan Peninsula or Russia, is combined with depressions in the Mediterranean Sea or an anticyclone in the East Europe together with the low pressures in the Aegean sea [15].

In spring, the application of FA to air temperature and precipitation resulted in three and four factors, respectively, explaining the 86% and 63% of the total variance of each parameter. In the process, CCA was applicable on the two sets of factor scores and three canonical pairs were found out, but two of them are statistically significant at 95% confidence level with canonical correlations r = 0.8 and r = 0.5 respectively. Following the previous analysis one canonical pair is interpretable. The resulted pattern reveals an inverse relation between air temperature and precipitation regimes. The air temperature decreases in the whole area of Greece, except the Central and South Aegean Sea, while high precipitation appears over Western and North-Western Greece. That period of the year the frequency of depressions moving over Greece decreases because of the increase of the anticyclone expansions at the east basin of the Mediterranean Sea. The combination of the anti-cyclone expansions with depressions existing in the Eastern Mediterranean and Asia Minor is a very common phenomenon. The collision of air masses of different properties results in great temperature variations.

The same procedure was followed in summer. Two factors for air temperature and four factors for precipitation were derived by FA, explaining the 75% and 55% of the total variance, respectively. The application of CCA on the two sets of factor scores results in two canonical pairs, while one of them is statistically significant at 95% confidence level with canonical correlation r = 0.6. This canonical pair (W1, V1) is presented in Figure 4. It is obvious that in the western and southern regions of Greece appear high temperatures, while the central continental Greece is under low precipitation regime. As mentioned before, the tracks of depressions are shifted to the north of the country and, of course, the polar front. The prevailing weather type in summer is that of Etesians winds (periodical winds of the north section). This type is established in Greece, when a North Atlantic anticyclone extended over Europe covering the Balkans is combined with the Indian low over Asia Minor and the Eastern Mediterranean Sea. The blow of Etesians winds transfers polar continental (cP) air masses to Northern Greece and the result is the appearance of precipitation and frontal thunderstorms. Another effect of the Etesians regime is the summer drought and the uniform weather conditions in Greece.

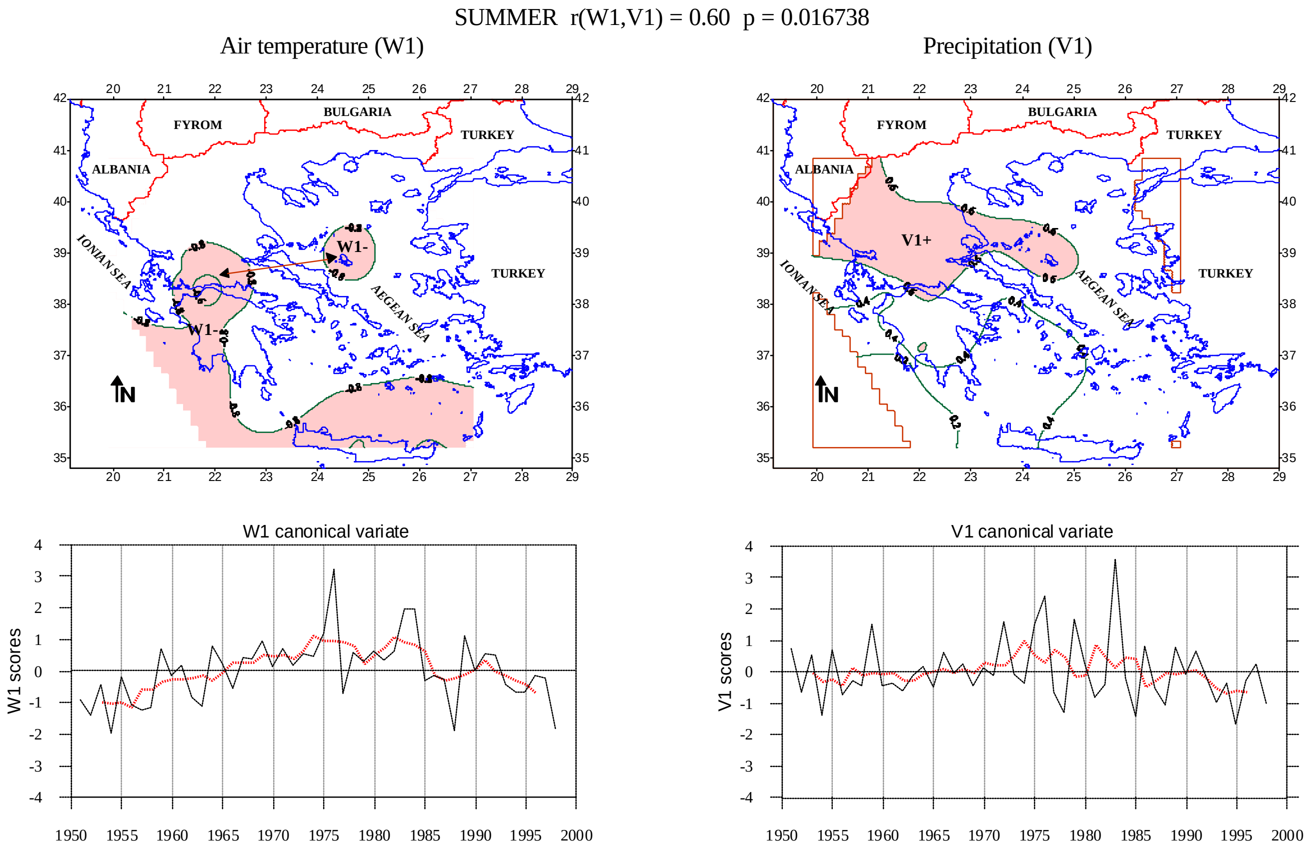

FIGURE 4 - As in Figure 2, but for summer.

At the western regions as the interior of the continental land the Etesians are of north-west direction and they are weaker than the ones in Aegean Sea and less frequent, so the air temperature regime at the Western Greece is independent of the Etesians blow.

During fall, the air temperature is described well with two factors (83% of the total variance) and the precipitation with five factors (64% of the total variance). Applying CCA to the two sets of factor scores, two canonical pairs were found out, but only one pair is statistically significant at 95% confidence level with canonical correlation r = 0.6. In that case the resulting pattern shows a link between the high temperatures at the South-East Aegean Sea and the high precipitation at the North and Central Aegean Sea. The prevailing weather type in fall is of an anticyclone covering the East and South-East Europe and Balkans. If the presence of the anticyclone combines with a depression at the Aegean Sea, then high precipitation occur at the North Aegean, while the air temperature increases, because the warm section of the depressions covers the region.

CONCLUSIONS

By the application of FA at first and then CCA to the seasonal air temperature and precipitation data in Greece, for the period 1950-2000, it was found that in wintertime a relation between air temperature and precipitation regime exists. The first canonical pair indicates that when high air temperatures occur almost all over Greece high precipitation falls at the west, north and east regions of Greece. This is due to the depressions, which have tracks to the north or through Greece. The second canonical pair reveals an inverse relation between air temperature and precipitation, that is, the North Greece is under low air temperatures while high amount of precipitation occurs at the South Aegean Sea depending on the depressions having tracks mostly south of Greece covering the country with their north section.

In spring and summer the resulting patterns show an inverse relation between air temperatures and precipitation. That period of the year the frequency of depressions moving over Greece decreases because of the increase of the anticyclone expansions at the east basin of the Mediterranean Sea.

In fall, the investigated regimes are related in a way that a link exists between the high air temperatures at the South-East Aegean Sea and the high precipitation at the North and Central Aegean Sea. The prevailing weather type in fall is of an anticyclone covering the East and South-East Europe and Balkans and of course the depressions begin having tracks through Greece.

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