Spatial and Temporal Distribution of Air Temperature over the Balkan Peninsula*

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ABSTRACT: In this study the spatial and temporal distribution of the 5º x 5º gridded air temperature, over the Balkan Peninsula, (10ºE-30ºE, 35ºN-50ºN) are presented, using the Principal Components Analysis, (PCA). The goal of that research is to pinpoint the regionalization of Balkans concerning the covariability of surface air temperature.

Eleven 5º x 5º grid box time series of air temperature, (annual and seasonal data), covering a period of 133 years (1858-1990) are grouped in three components representing the climatic characteristics of the North-West, South and North-East regions of the examined area. The spatial distribution of the grid box time series has the same pattern for the annual, winter and spring temperature variations, but differs for summer and autumn ones where the first principal component represents the North-East and South region respectively.

Air temperature variations during the period 1858-1990 are also presented on a basis of the annual and seasonal time series of the scores for the significant principal components.

Key-words: *Air temperature, spatial and temporal distribution, Principal Components Analysis, Balkan peninsula*.

ΠΕΡΙΛΗΨΗ: Στην εργασία αυτή παρουσιάζεται η χωρική καί χρονική κατανομή της θερμοκρασίας του αέρα κιβωτίων πλέγματος 5 ºx 5º, για την Βαλκανική χερσόνησο, (10ºE - 30ºE, 35ºN - 50ºN), εφαρμόζοντας την Ανάλυση σε Κύριες Συνιστώσες (PCA). Ο σκοπός της έρευνας ήταν να αναδειχθούν περιοχές των Βαλκανίων που παρουσιάζουν ομοιότητες στην μεταβλητότητα της επιφανειακής θερμοκρασίας του αέρα.

Οι χρονοσειρές της θερμοκρασίας του αέρα (ετήσιες και εποχικές τιμές) από έντεκα κιβώτια πλέγματος 5º x 5º, για χρονική περίοδο 133 ετών (1858-1990) ομαδοποιούνται σε τρεις κύριες συνιστώσες, που αντιπροσωπεύουν τα κλιματικά χαρακτηριστικά του Βορειο-Ανατολικού τμήματος της εξεταζόμενης περιοχής. Η χωρική κατανομή των χρονοσειρών της θερμοκρασίας του αέρα έχει την ίδια μορφή όσον αφορά το έτος, τον χειμώνα και την άνοιξη, ενώ διαφοροποιείται για το θέρος και το φθινόπωρο, όπου η πρώτη κύρια συνιστώσα αντιπροσωπεύει το Βόρειο-Ανατολικό και Νότιο τμήμα των Βαλκανίων, αντίστοιχα.

Οι χρονικές μεταβολές της θερμοκρασίας του αέρα, κατά την διάρκεια της περιόδου 1858-1990, εξετάζονται επίσης στη βάση των ετήσιων και εποχικών χρονοσειρών των κανκνικοποιημένων τιμών των σημαντικών κυρίων συνιστώσων.

Λέξεις-κλειδιά: *Θερμοκρασία αέρα, χωρική και χρονική κατανομή, Ανάλυση σε Κύριες Συνιστώσες, Βαλκανική χερσόνησος.*

INTRODUCTION

Climatic changes are in the center of interest of many researchers, because the interpretation of their results and the understanding of the causes which deal with them, help scientists to construct and check climatic models which aim to forecast the future climate in order to avoid hazards, program the agricultural production in a better way as well as minimize the lack of water and energy.

A lot of studies have been carried out, concerning temperature variations over the whole northern hemisphere (JONES *et al*., 1982, 1983; KELLY *et al*., 1982; SCHONWIESE, 1978, 1983), as well as the area of Mediterranean Sea (MAHERAS, 1988; REPAPIS *et al*., 1988; BARTZOKAS *et al*., 1990). It is well known (JONES & BRIFFA, 1992; VINIKOV *et al*., 1990; WMO-No 838; IPCC, 1995) that during the 20th century the air mean temperature at the earth's surface has raised about 0.6 ºC. The temperature remains at low levels from about the end of 19th century or the beginning of the 20th century, which defines the end of the "little ice age" and after that shows a rapid increase till about 1940. Thereafter the temperature appears a low decrease till about the middle of the 70's when a rapid increase comes, which is continued till nowadays.

Especially in this paper the distribution of the air

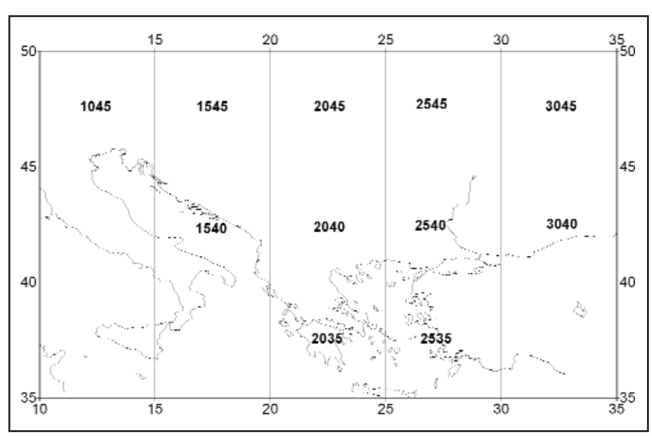


Fig. 1. Positions of the grid boxes, which cover the Balkan Peninsula.

* Χωρική και χρονική κατανομή της θερμοκρασίας του αέρα, στη Βαλκανική Χερσόνησο.

temperature over the Balkans is examined on a basis of 5°x 5° gridded data, which are more reliable because they come from a large number of stations among the limits of the grid box and have no missing data. Applying the method of PCA on the annual and seasonal matrix data in the assessment of Balkans regionalization, three regions in Balkans are determined with significantly covariant air temperature time series.

DATA AND ANALYSIS METHOD

The 5° x 5° gridded monthly air temperature data, concerning the period of 1858-1990 and covering the area included by the limits 10°E - 30°E, 35°N - 50°N, were taken by the Climatic Research Unit of the East Anglia University, (CHADWYCK-HEALEY, 1992). They are anomalies of the mean monthly air temperature from the respective mean values of the period 1961-1990.

A PCA can be specified in at least six basic operational modes, depending on which parameters are chosen as variables, individuals/cases and fixed entries, for example S-mode, T-mode, R-mode, etc. In the S-mode, stations are selected as variables, time is selected as individuals/cases and parameters as fixed entries.

The eleven grid boxes, which cover the wide Balkan Peninsula, appear in the Fig. 1. From the monthly data, the annual and seasonal ones were evaluated in order to be the initial matrix data for PCA, that is, five matrices of 133 x 11 data with 133 years and 11 grid boxes for annual, winter, spring, summer and autumn temperature data, (S-mode).

The PCA is a widely used statistical method and the main applications of the analysis are: (1) to reduce the number of variables and (2) to detect structure in the relationships between variables, that is to classify variables. Applying the method on the initial matrix data the PC loadings are derived, which can be interpreted as correlations between the original variables and PCs, and come out in decreasing order of their importance. That means that the first PC explains the greatest of the variance of the original data and so on. The number of the derived PCs depends on the pattern of the scree plot, which is a simple line plot of the successive eigenvalues, (the i-th PC comes out to be the eigenvector associated with the i-th largest eigenvalue of the correlation matrix of the variables). Thus no more than the number of PCs to the left of the point where the decrease of eigenvalues appears to level off, should be extracted.

In order to obtain a clear pattern of loadings, that is, PCs that are somehow clearly marked by high loadings for some variables and low loadings for others, various rotational methods are used. The method that is most commonly used is the orthogonal rotation Varimax, (RICHMAN, 1986), which is aimed to at maximizing the variance of the squared normalized loadings across variables for each PC.

SPATIAL DISTRIBUTION OF THE AIR TEMPERATURE

In Table 1, the PC loadings after orthogonal Varimax rotation for annual, winter, spring, summer and autumn temperature data, are presented. The scree plot, the rule (for eigenvalue ≥1), and the percentage of the total explained variance are the criteria, which define the number of the PCs.

The loadings with values over 0.7 are shaded so that the groups of grid boxes seem clear. For each PC the eigenvalue (EIGVL) and the explained variance (EXPL. VAR.(%)) are also presented in Table 1.

The total explained variances of the PCs for annual and seasonal data are very high and range from 94.63 % (Summer) to 97.46 % (Spring).

TABLE 1
PC loadings after orthogonal Varimax rotation, eigenvalues and total variance explained of the first three Principal Components.

VARIABLES	PC LOADINGS														
	ANNUAL			WINTER			SPRING			SUMMER			AUTUMN		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
1. GRID1045	**0.95**	0.05	0.16	**0.95**	0.05	0.25	**0.96**	0.11	0.15	0.09	**0.94**	0.13	0.07	**0.96**	0.16
2. GRID1540	**0.77**	0.61	0.13	**0.75**	0.61	0.20	**0.72**	0.62	0.24	0.17	**0.72**	0.64	0.54	**0.78**	0.25
3. GRID1545	**0.92**	0.12	0.35	**0.92**	0.17	0.35	**0.88**	0.17	0.42	0.32	**0.90**	0.25	0.24	**0.88**	0.38
4. GRID2035	0.23	**0.94**	0.09	0.16	**0.95**	0.06	0.27	**0.94**	0.15	0.18	0.30	**0.90**	**0.89**	0.33	0.24
5. GRID2040	0.59	**0.67**	0.41	0.61	**0.68**	0.37	0.54	**0.68**	0.47	0.44	0.52	**0.70**	**0.64**	0.57	0.48
6. GRID2045	**0.82**	0.15	0.54	**0.82**	0.22	0.51	**0.73**	0.21	0.64	0.59	**0.73**	0.29	0.30	**0.74**	0.59
7. GRID2535	-0.07	**0.91**	0.33	0.01	**0.94**	0.22	0.02	**0.93**	0.33	0.43	0.10	**0.85**	**0.89**	0.09	0.39
8. GRID2540	0.30	0.62	**0.70**	0.42	**0.67**	0.58	0.29	0.65	**0.69**	**0.79**	0.25	0.52	0.61	0.32	**0.71**
9. GRID2545	0.61	0.15	**0.76**	0.63	0.23	**0.73**	0.52	0.23	**0.81**	**0.85**	0.43	0.21	0.29	0.50	**0.81**
10. GRID3040	0.08	0.56	**0.80**	0.26	**0.69**	0.65	0.09	0.58	**0.79**	**0.89**	0.05	0.36	0.57	0.16	**0.78**
11. GRID3045	0.45	0.14	**0.86**	0.50	0.22	**0.82**	0.37	0.25	**0.88**	**0.94**	0.22	0.13	0.27	0.33	**0.89**
EIGVL	7.60	1.98	1.02	8.16	1.88	0.61	8.16	1.64	0.92	7.70	1.59	1.12	8.50	1.42	0.76
EXPL.VAR.(%)	69.05	17.96	9.26	74.19	17.12	5.57	74.19	14.89	8.38	69.98	14.49	10.16	77.23	12.89	6.95

a. Annual air temperature distribution

As shown in Table 1, concerning annual data, the PC1 explains the 69.05 % of variance. The computed rotated loadings appear high values at the northwest region of the Balkan Peninsula, that is, the region included by the grid boxes GRID1045, GRID1540, GRID1545 and GRID2045 (Fig. 2). These grid boxes are influenced by the continental European and middle northern Atlantic air masses.

The second principal component (PC2) explains the 17.96 % of variance and represents the south region of Balkans, (the Greek peninsula and the Aegean sea), that is the grid boxes GRID2035, GRID2040, GRID2535 which appear high values for the estimated rotated loadings. It is apparent the influence of Mediterranean and the Aegean sea in the formation of this temperature pattern. The isopleths of these loadings are lined according to geographical latitude (Fig. 2).

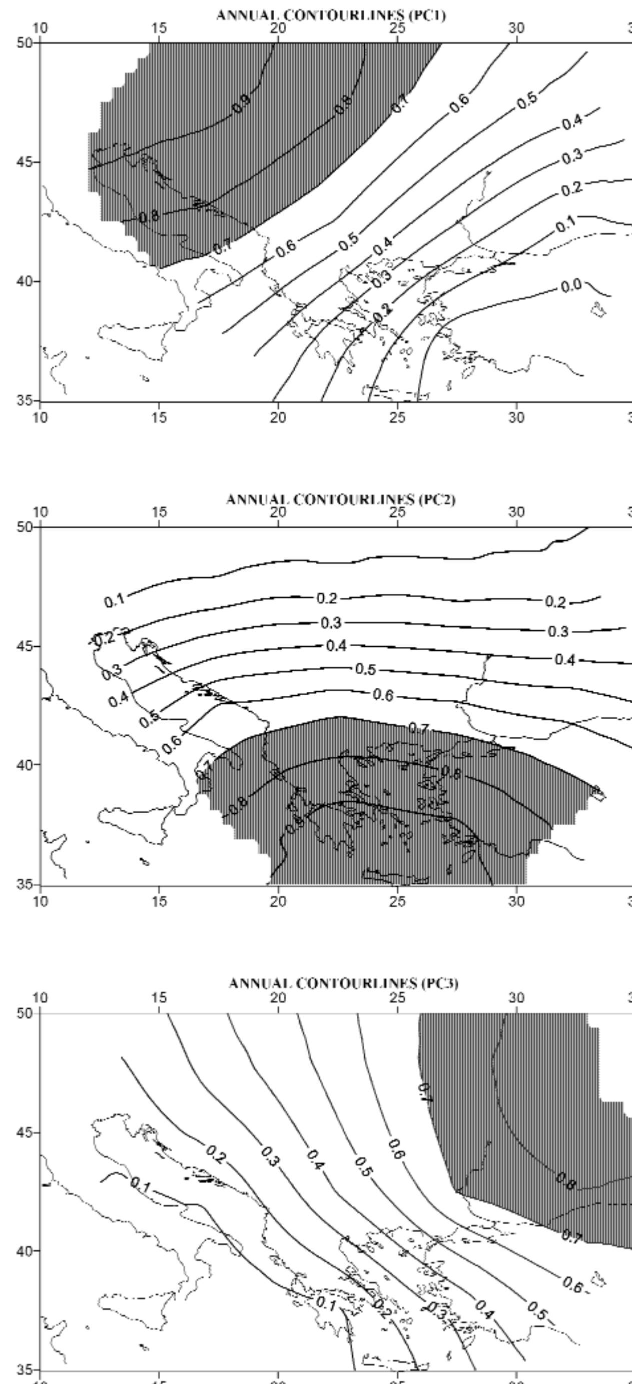
The third principal component, explaining the 9.26 % of variance appears high values for the rotated loadings of the grid boxes GRID2540, GRID2545, GRID3040, GRID3045, that is the north-east region of Balkans (Fig. 2) which is influenced by the continental air masses in combination with those formed over the Black sea.

b. Seasonal air temperature distribution

The spatial air temperature distributions for winter and spring, summer and autumn are presented in Figs 3, 4, respectively. It is obvious that the winter and spring temperature data appear the same distribution pattern, dividing the investigated area in three regions: the northwest, the south and the northeast, which are represented by the first, second and third PC respectively.

Winter and spring PC1 explains the same percentage 74.19 % of total variance as shown in Table 1, while PC2 explains the 17.12 % and 14.89 % of total variance for winter and spring respectively. The cyclonic circulation plays important role for the temperature distribution interpreted by the second principal component. The number of PCs in winter season could be two, explaining the 91.31 % of the cumulative variance, because of the eigenvalue for the third component which is Θ1, resulted in temperature distribution pattern which would shown the two sections of the Balkan peninsula, the north and the south one. High values of the rotated loadings for spring PC3, which explains the 8.38 % of the total variance, appear at grid boxes: GRID 2540, GRID2545, GRID3040 and GRID3045.

In summer the distribution pattern changes and the first component, explaining the 69.98 % of the total variance, corresponds to northeast region. The anticyclonic conditions are now apparent and influence the temperature distribution in combination with the local geographical factors. The second PC explains the 14.49 % while the third one explains the 10.16 % of the total variance. PC2 explains temperature variations for the grid boxes in north-west region as component PC1 does for annual, winter and spring data while component PC3, explaining the 10.16 % of the variance, corresponds to south grid boxes as annual, winter and spring PC2 does. Generally speaking a circular distribution pattern movement is remarked as the passage from winter and spring to summer occurs.



2.1

2.2

2.3

Fig. 2. Annual spatial distribution (contourlines) for the loadings of the first (PC1), second (PC2), and third (PC3) principal component.

For the autumn the first three components are significant explaining the 77.23 %, 12.89 % and 6.95 % of the total variance, respectively.

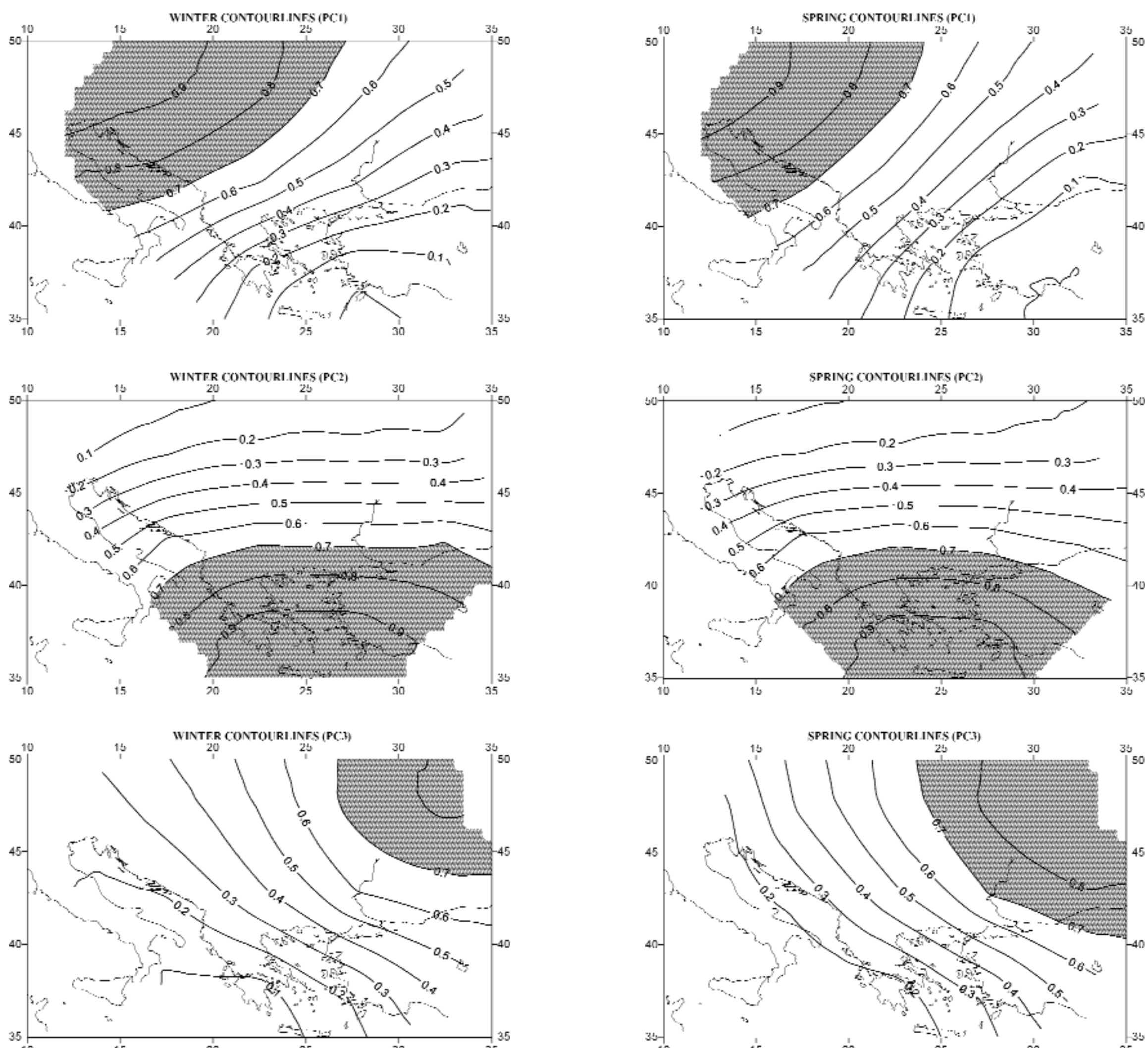
The autumn contour lines of the rotated loadings for the first and third PC have the same pattern with the summer contour lines of loadings for the third and first PC respectively while the temperature regime as it is interpreted by the PC2 seems the same for summer and autumn temperature data. From that point it is useful to be remarked that the explained percentage of the total variance (77.23 %) for the autumn PC1 is the highest of all in other seasons.

TEMPORAL DISTRIBUTION OF THE AIR TEMPERATURE

Air temperature variations during the period 1858-1990 are studied on a basis of the time series scores for the significant principal components, which correspond to annual and seasonal data. As shown in figures 5, 6, 7, the time series of the individual scores (thin curve), along with eleven year moving average (wide curve), for the three principal components are plotted.

a. Annual temperature distribution

Fig. 5 presents the annual march of the scores of the three principal components. Positive values for the first factor PC1 represent high temperatures for the grid boxes GRID1045, GRID 1540, GRID1545, GRID2045, while negative values corresponds to low temperature at the same grid boxes. An increasing trend from 1875 to 1948 is obvious with peak in 1948, and then a sharp decrease happens till 1960. For the next thirty years the values oscillate around the mean. The period of the temperature increase is mentioned by other studies concerning Medi-



3.1 3.2 3.3 3.4 3.5 3.6

Fig. 3. Winter and Spring spatial distribution (contourlines) for the loadings of the first (PC1), second (PC2), and third (PC3) principal component.

terranean sea and Northern Hemisphere, (Maheras, 1988; Arseni, 1973; Metaxas, 1974; Wigley & Farmer, 1982; Jones & Kelly, 1983; Schonwiese, 1983).

The interpretation of PC2, shows a decrease from the beginning of the investigated period lasting until the end of the 1900. Then an ascending trend appear until 1928 and from there on the temperature keeps positive values around the mean. Afterwards a sharp temperature drop begins, lasting until the end of 1990.

The northeast group, represented by PC3, appears a different time variation. From the beginning of the analyzed period, the scores remain nearby the mean and indicate a relative stability until the end of the decade 1910-1920. Then negative values of the scores appear with some fluctuations and an ascending trend follows, beginning from the end of 1940 and lasting till the end of 1980.

b. Seasonal temperature distribution

In Winter, the scores for PC1 remain below the mean from the beginning of the investigated period to the end of 1900, then positive values appear till the middle of 1930 and an oscillation around the mean continues till nowadays. Generally speaking the score time series for PC1 show only slight variations.

The same pattern appears for the south region expressed by PC2. The temperature variations in northeast region (PC3) are of low level with an exception during the period 1920-1930 where a fall appears and afterwards an ascending trend follows.

In Spring the score variations for the three principal components indicate the same characteristics as the annual ones for the same group. A maximum, like annual one, appears to the end of 1940, concerning the score

4.1 4.4
4.2 4.5
4.3 4.6

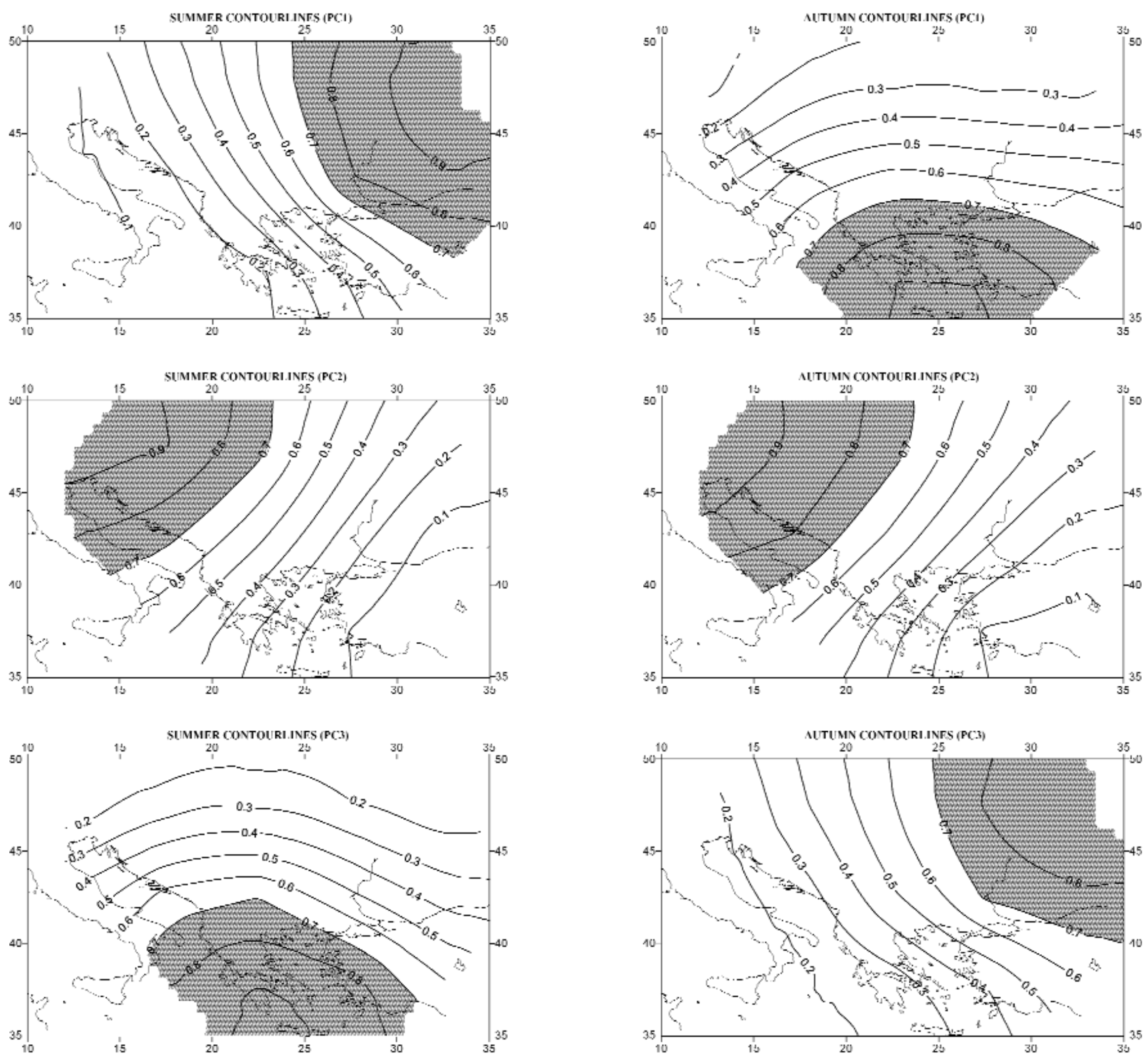


Fig. 4. Summer and Autumn spatial distribution (contourlines) for the loadings of the first (PC1), second (PC2), and third (PC3) principal component.

time series for PC1 and interpreting the scores for PC2, a descending trend is revealed from the beginning of the investigated period till the end of the decade of 1910, quite similar to the annual one. Then, the scores are quite close to the mean, meaning that the temperature appears relative stability for the last 60 years.

In Summer, and autumn the interpretation of scores for PC1 shows a temperature minimum in the middle of the 1910's and then an abrupt ascending trend follows till the end of 1938. A second temperature minimum appears at the end of 1948 for summer, while slight variations domain till the end of 1968 for autumn. Then a falling trend is obvious till 1990. PC2 scores present small variability around the mean with a maximum at 1948 and then keep negative values till 1988, for the summer season.

On the other hand the autumn PC2 scores have small deviations from the mean and generally speaking preserve negative values for the first half of the examined period while positive ones appear at the second half. The characteristic of the summer PC3 scores is the temperature minimum, which takes place at 1900. On the contrary the autumn PC3 scores appear a stationary pattern.

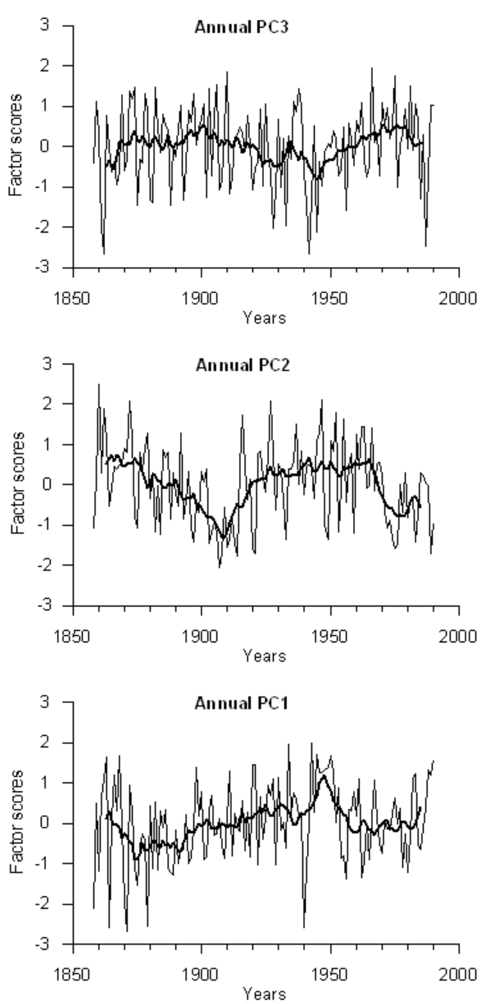


Fig .5. Time series of annual scores (thin curve), along with 11 year moving average filter (heavy curve), of the three principal components.

CONCLUSIONS

The regionalization of the Balkans concerning the surface air temperature was achieved by the application of PCA method on annual and seasonal matrix data (133 x 11) with 133 years and 11 grid boxes. Three regions were determined with significantly covariant air temperature timeseries. The annual spatial distribution of the rotated loadings for the three principal components interprets in three characteristic regions of Balkans that is the northwest, the south, and the northeast. Regarding the seasonal spatial distribution the winter and spring data reveal the same distribution pattern as the annual one and generally speaking a circular distribution pattern movement is remarked as the passage from winter and spring to summer occurs. The total explained variances by the principal components for annual and seasonal gridded temperature data are very high and range from 94.63 % (Summer) to 97.46 % (Spring).

Finally the assessment of the scores for the PCs indicated that the gridded air temperature for Balkan area presents a variability with small fluctuations around the mean and a slight ascending trend is apparent concerning the annual scores of PC1 (north-west region), while descending trends domain for the PC2, (south region), and PC3 (north-east) annual scores, till nowadays.

However, it is remarkable to pinpoint that for the mid-range IPCC emission scenario, IS92a, assuming the "best estimate" value of climate sensitivity [In IPCC reports, climate sensitivity usually refers to long-term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent CO_2] and including the effects of future increases in aerosol concentrations, models project an increase in global mean surface temperature relative to 1990 of about 2 °C by 2100. Combining the lowest IPCC emission scenario (IS92c) with a "low" value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1°C by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a "high" value of climate sensitivity gives a warming of about 3.5 °C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Because of the thermal inertia of the oceans, only 50-90 % of the eventual equilibrium temperature change would have been realized by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilized by that time (IPCC, 1995).

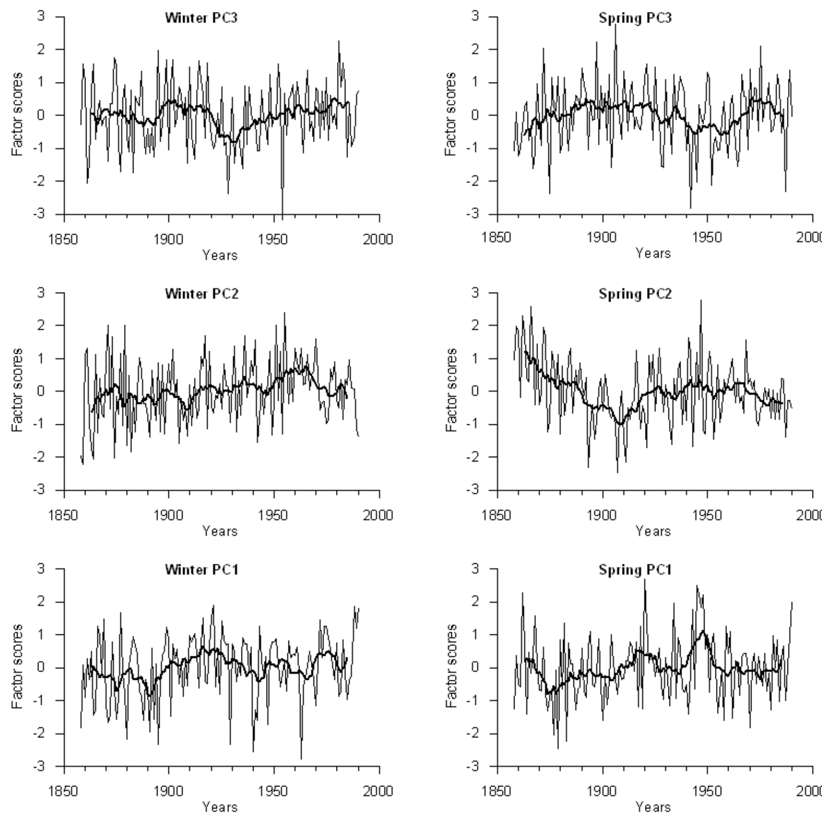


Fig. 6. Time series of winter and spring scores (thin curve), along with 11 year moving average filter (heavy curve), of the three principal components.

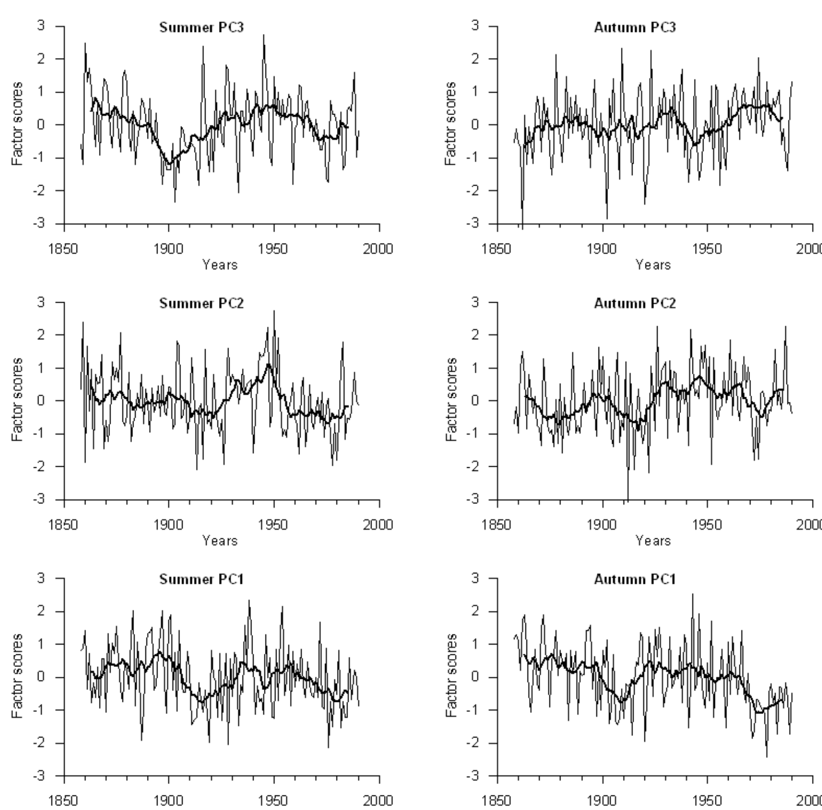


Fig. 7. Time series of summer and autumn scores (thin curve), along with 11 year moving average filter (heavy curve), of the three principal components.

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