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Genetic climatic regionalization of the Balkan Peninsula using cluster analysis

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Abstract: Sea Level Pressure (SLP) data for the period 1950–2012 at 61 stations located in or around the Balkan Peninsula was used. The main concept is that intra-annual course of SLP represents the best different air masses that are situated over the Balkan Peninsula during the year. The method for differentiation of climatic zones is cluster analysis. A hierarchical clustering technique–average linkage between groups with Pearson correlation for measurement of intervals was employed in the research. The climate of the Balkan Peninsula is transitional between oceanic and continental and also between subtropical and temperate climates. Several major changes in atmospheric circulation over the Balkan Peninsula have happened over the period 1950–2012. There is a serious increase of the influence of the Azores High in the period January–March, which leads to an increase of SLP and enhances oceanic influence. There is an increase of the influence of the north-west extension of the monsoonal low in the period June–September. This leads to more continental climate, but also to more tropical air masses over the Balkan Peninsula. Accordingly, the extent of subtropical climate widens in northern direction. There is an increase of the influence of the Siberian High in the period October–December. This influence covers central and eastern part of the peninsula in October and November, and it reaches western parts in December. Thus, the climate becomes more continental.

Keywords: genetic classification, regionalization, Balkan Peninsula, cluster analysis, Sea Level Pressure, circulation indices

1 Introduction

There are many climatic classifications in international scientific literature. In general, they are divided into two groups based on employed methods–empiric or genetic (Oliver and Wilson, 1987; Arnfield, 1988). The first group describes and classifies climates on Earth based on specific, measurable information–predominantly air temperature and precipitation. An example of such classification is that of Köppen (1936). Genetic classifications are based on factors that determine the climate in a given place–radiation balance of the Earth's surface, atmospheric circulation, etc. The most popular genetic classifications are based on spatial distribution and movement of different air masses. This is the area of work of

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Strahler (1951), Alisov (1962) and others. Alisov and Poltaraus in their *Climatology* (1962) differentiate four major types of air masses–equatorial, tropical, temperate and arctic. In addition to these four zones there are three transitional in which two different types of air masses alternate during the year–subequatorial (equatorial and tropical air masses), subtropical (tropical and temperate) and subarctic (temperate and arctic) zones. There are three main fronts (border areas) within the planet–tropical, polar and arctic. These fronts separate the four main types of air masses. They also move within the year, and the areas between their summer and winter position are actually the areas of transitional climatic type. The main problem of all genetic classifications is the impossibility to differentiate hierarchical units based on an objective numerical criterion. In most cases, the differentiation is subjective. The classification, proposed by Alisov, is based on winter and summer position of the three planetary fronts in the respective hemisphere. This method earns relatively good results as regards to determination of the main hierarchical units, but cannot be used for differentiation of regions at a lower level. There are also attempts to typify air masses based on certain quantitative parameters related to air temperature and precipitation, but in most cases these attempts have not proved feasible and effective.

In recent decades, climate regionalizations tend to be based more on objective methods and principles. However, the subjective factor is still present due to inhomogeneities in measurement data, insufficient density of meteorological stations and hence the need for subjective approach in determining the boundaries of the different regional entities. In this aspect, the role of GIS methods, which support the process of defining and drawing the boundaries, increases. Five basic principles of regionalization are postulated in the climate regionalization of China (Zheng *et al*., 2010): zonal and azonal integration, genetic unity and relative consistency of regional climate integration, comprehensiveness and integration of leading factors, bottom-up and top-down integration, and spatial continuity and small patch omission. Dezfuli (2011) derives three basic principles of regionalization: the regions are homogeneous and geographically contiguous, the size of regions is consistent with problem-specific size constraints, and the total number of regions is consistent with the inherent physical properties of interest. All these principles were taken into consideration in elaborating this regionalization of the Balkan Peninsula. There has been an increased usage of statistical methods in recent years, including mainly Principal Components Analysis (PCA) and Cluster Analysis (CA). PCA is typically applied when there are more variables (e.g., different characteristics of air temperature and precipitation) in order to reduce their quantity, while maintaining the original data variability. This approach is used in climate regionalization of various parts of the world–Pennsylvania, USA (White *et al*., 1991), central-northeastern region of Mexico (Pineda-Martínez *et al*., 2006), Saudi Arabia (Almazroui *et al*., 2015), Qazvin province, Iran (Shahriar *et al*., 2015). If there are fewer variables (one), CA is the more appropriate method to be used. CA methods can be divided into two main groups–hierarchical and non-hierarchical, hierarchical methods having two main approaches–agglomerative (bottom-up) and divisive (top-down) (Badr *et al*., 2015). The most appropriate method for climate regionalization is agglomerative hierarchical clustering. This method is used by Badr *et al*. (2015) for regionalization of Africa, and also by Bieniek *et al*. (2012) for regionalization of Alaska, Dambul and Jones (2008) for regionalization of Borneo, etc.

Climatic regionalizations of certain regions of the Earth are characterized in that they are carried out within the borders of individual countries. Hierarchical units at lower level very often do not match across the border of two countries. Sometimes there is a disagreement even within the main hierarchical units. The causes for this most often are due to different classification (genetic, empiric or combination of both) methods used in different countries or within a given country. The Balkan Peninsula situation illustrates very well these problems. In principle, the territory of the peninsula is difficult for regionalization because it is situated on the border between temperate and subtropical climates, and on the border between oceanic and continental influences. Climatic regionalizations of Bulgaria are based on mixed (genetic and empiric) methods. Only in the works of Kirov (Kirov, 1929; Kirov and Kyuchukova, 1955) an entirely empiric classification system is used based on the distribution of air temperature and precipitation. Other authors (Dimitrov, 1968; Sabev and Stanev, 1963; Stanev *et al*., 1991; Topliisky, 2006; Velev, 1990) use genetic classification of Alisov but differentiate various hierarchical units based on air temperature and intra-annual course of precipitation. They have accepted that air temperature should represent the radiation factor and precipitation course–the circulation factor. According to the most common opinion Bulgaria is divided into three main areas–temperate-continental (northern Bulgaria and the area around Sofia), transitional (Upper Thracian Plain, areas around Kyustendil and Blagoevgrad) and continental-Mediterranean (southern parts of Bulgaria and the entire Black Sea coast). However, the climatic regionalization of Romania (Posea, 2006), which is based on roughly the same principles, reveals certain differences. A large (western) part of the Danubian Plain belongs to a transitional Mediterranean climate. The area around Timisoara also belongs to this climatic zone. On the other hand, climatic regionalization of Serbia (Rakićević, 1980) shows that the area, which is near Timisoara (Kikinda), has a temperate oceanic climate. Towards the border with Croatia, the area north of the Danube has temperate oceanic climate, and the area south of the river has temperate continental climate. However, the regionalization of Croatia (Šegota and Filipčić, 2003), which is based on empirical methods (Köppen classification) shows that the area near the border with Serbia belongs to only one type of climate–temperate humid with warm summer. The adjacent area of Bosnia and Herzegovina (Alibegovic-Grbic, 2009) is characterized by temperate continental climate. In the climatic regionalization of Slovenia (Ogrin, 1996; Ogrin, 2004), which is of mixed type, the bigger part of the country belongs to temperate continental climate. In this sense, the northern and eastern part of Croatia, classified by Köppen's classification as temperate humid with warm summer should correspond to temperate continental climate. The Adriatic Sea coast belongs to a transitional towards subtropical (Slovenia, Croatia) or subtropical (Croatia, Bosnia and Herzegovina, Montenegro – Prvi nacionalni izvještaj Crne Gore o klimatskim promjenama prema okvirnoj Konvenciji Ujedinjenih nacija o klimatskim promjenama 2010, Albania-Merkoci *et al*., 2010) climate. Climatic regionalization of Macedonia (Zikov, 1995) shows that southwestern parts of the country belong to temperate continental climate. However, the two neighboring countries, Albania and Greece (Kokkini *et al*., 2004) have typical subtropical climate. There are also some problem areas in climatic regionalizations of Turkey (Iyigun *et al*., 2013; Unal *et al*., 2003) like Black Sea coast, which is included in the temperate climate, while there is a subtropical climate just north of it (Yalta). All these examples show the large discrepancies that exist in climatic regionalizations of different countries.

The main aim of the study is by using one classification method to create a unified regionalization of the Balkan Peninsula. Several tasks were performed in order to achieve this aim. A genetic classification was accepted as basis for climatic regionalization. The main differentiation criterion is atmospheric circulation characterized by prevailing air masses in different months of the year. The numerical criterion, which describes atmospheric circulation, is intra-annual course of sea level atmospheric pressure (SLP). This approach is new to science, as it accomplishes a genetic classification by means of a numerical criterion. Also this numerical criterion (SLP) is not typical for climate regionalization (the most commonly used are air temperature and precipitation). The basic classification method is cluster analysis, which enables an objective grouping of different stations. Another major objective of this study is to show temporal dynamics of borders between the different hierarchical units, because climate system is variable in time. This approach is also new in the regionalization of the Balkan Peninsula because current regionalizations are temporally static.

2 Data and methods

SLP data at 61 stations located in or around the Balkan Peninsula (Figure 1) are used in this research.

The period of study is 1950–2012. Station concentration in Bulgaria is higher, which is associated with the larger volume of available information gathered from the Annual

Figure 1 Location of the stations

Meteorological Books (Annual Meteorological Books). Internet and personal contacts were data sources for stations outside Bulgaria. Data were checked for homogeneity by the following main methods–method of differences, non-parametric criterion of Mann-Whitney (Wilks, 2006) and investigation of the history of the station, where possible. SLP is spatially stable, allowing a correct homogenization and recovery of missing values. On the other hand, SLP is very sensitive to relocation of barometer in vertical direction. Some doubts about the accurate determination of altitude of barometer at certain stations and hence of corresponding values of SLP remain. However, this had no significant influence on the clustering process. Inhomogeneities were detected and corrected using the method of differences at the following stations: Pleven (01.1953–06.2000), Vratsa (06. 1960–06.1983), Veliko Tarnovo (05.1975–12.1992), Varna (01.1950–09.1960), Burgas (1950–53), Pazardzhik (1973–89), Sofia (01.1955–05.1970), Kyustendil (1950–81), Sandanski (01.1950–03.1972), Kardzhali (1973–81, 04–12.2012), Sliven (1953–70), Haskovo (1950–67, 03.1973–12.1986), Kazanlak (1952–66), Thessaloniki (1950–85), Edirne (1950–53, 1963–86), Zagreb (1965–2008), Belgrade (1950–57, 1965–87), Split (1950–2008), Podgorica (1950–93), Skopje (1951–93), Nis (1950–58, 01.1988–11.2009), Osijek (1950–64, 10.1976–12.1987), Rijeka (1950–2008), Cluj (01.1951–10.1996), Sibiu (1951–57), Bucharest (1982–2008), Constanta (1950–70, 06.1975–08.2005), Craiova (01.1973–09.1985, 2009–2012), Istanbul (1950–55), Izmir (1950–59, 1971–2006), Çanakkale (1951–86), Novi Sad (01.1967–02.1988), Buzau (1973–81), Galati (1959–67), Alexandroupolis (01.1967–07.1986), Athens (01.1950–03.1972), Larissa (11.1953–06.1996), Methoni (1951–65, 11.2003–06.2011), Ljubljana (1961–2006), Limnos (1951–77), Gospic (06.1950–12.1999), Trieste (1951–56, 1959–60, 1971–80), Lastovo (05.1958–12.1973), Araxos (2001–2012), Timisoara (06.1952–01.1996), Bistrita (1951–70, 2009–2012), Negotin (1951–57, 07.1981–12.2012), Dimitrovgrad (1950–2009), Valjevo (1957–88) and Vranje (06.1950–05.1974). The same method was used to fill some missing data at certain stations.

A zonal circulation index was used in the study. Method for its calculation is described in Nojarov (2013). It is after Tomingas (2002), who uses essentially the way of calculation of the NAO index. Monthly SLP data for the period 1950–2012 for 8 grid cells (2.5°×2.5° resolution) that surround the four grid cells, covering the territory of Bulgaria were used. In other words, the north side is covered by cells with coordinates 45°–47.5°N and 20°–30°E (4 in total); the south side is covered by cells with coordinates 37.5°–40°N and 20–30°E (4 in total). The values of the four northern cells were averaged to obtain the value for the north side. The same procedure was performed for the south side. The pressure data of each of the two sides were standardized by division of monthly pressure anomalies by the standard deviation for the investigated period. Zonal index was calculated as a difference between the standardized SLP values of the south and north sides. This means that positive values of the index indicate higher than normal west (zonal) transport of air masses and vice versa. The necessary data for sea level atmospheric pressure used to calculate the index for the period 1950–2012 were taken from reanalysis monthly data of The National Center for Atmospheric Research/National Centers for Environmental Prediction.

EA teleconnection index (pattern), directly related to the territory of Bulgaria, was also used in this study. The index was calculated by the NOAA National Weather Service Climate Prediction Center. The procedure and methods of calculation are shown on their website.

The East Atlantic (EA) pattern is the second prominent mode of low-frequency variability over the North Atlantic, and appears as a leading mode in all months. The EA pattern is structurally similar to the NAO, and consists of a north-south dipole of anomaly centers spanning the North Atlantic from east to west. The anomaly centers of the EA pattern are displaced southeastward to the approximate nodal lines of the NAO pattern. The positive phase of the EA pattern is associated with above-average precipitation over northern Europe and Scandinavia, and with below-average precipitation across southern Europe.

The method for differentiation of climatic zones used in this study is cluster analysis. One of the main problems in genetic classifications is the lack of specific numerical values that characterize a certain type of climate. Values of air temperature and/or precipitation have been used in previous studies, which, however, are not able to definitively represent a certain type of climate. That is why, it was accepted that intra-annual course of SLP represents the best different air masses that are situated over the Balkan Peninsula during the year. Low pressure is connected with cyclones, which in middle latitudes move along the polar front. High pressure is related to location of the main anticyclonic centers (the Azores High, the Siberian High), which determine the type of air masses over the peninsula continental, oceanic, temperate or tropical. A hierarchical clustering technique was used–average linkage between groups. Many authors have showed that this technique earns the best results in climatology (Iyigun *et al*., 2013; Unal *et al*., 2003; Wilks, 2006). Other clustering techniques and methods were also applied, but they showed a lot less reliable results. It was found also that for measurement of intervals the most suitable is Pearson correlation. A problem of SLP is that values are very sensitive to the altitude of barometer. As it was mentioned before there are some doubts about the correct determination of this altitude at some stations. A difference of 1 meter in vertical direction could lead to deviations of 0.1–0.2 hPa in SLP values. Pearson correlation is most insensitive to such deviations compared, for example, to Euclidean distance. Another statistical method employed in this study is trend analysis in order to detect tendencies in the circulation index. Calculated correlation coefficients reveal relationships between atmospheric circulation over Bulgaria and the EA teleconnection pattern. Spearman non parametric rank statistic was used to perform a reliable assessment of the significance of correlations.

3 Results and discussion

The main research period 1950–2012 was divided into two sub-periods: 1950–1986 and 1987–2012. The aim is to see changes in position of the borders between different climatic zones. The first sub-period can be defined as generally cold, the second–as generally warm. This was the main reason behind this separation. The analysis of every climatic zone will be performed in terms of the border between temperate and subtropical climates, and in terms of oceanic/continental influence. By definition subtropical climate consists of 6 months with tropical and 6 months with temperate air masses. The criterion for classification of a zone as subtropical was accepted to be that at least four months of the year should be with dominance of tropical air masses. Areas with 2–3 months with tropical air masses were accepted to belong to transitional zone between subtropical and temperate climates. An area belongs to temperate climate if there are less (one or none) months with tropical air masses.

Oceanic/continental influence has no limits within the year, so it was decided that where there is 4–8 months of influence of one or the other type of air masses the climate should be considered as transitional oceanic-continental. Areas with 3 or fewer months with influence of certain air masses belong to either oceanic or continental type of climate.

3.1 Sub-period 1950–1986

Results of cluster analysis and regionalization for the sub-period 1950–1986 are shown in Figure 2.

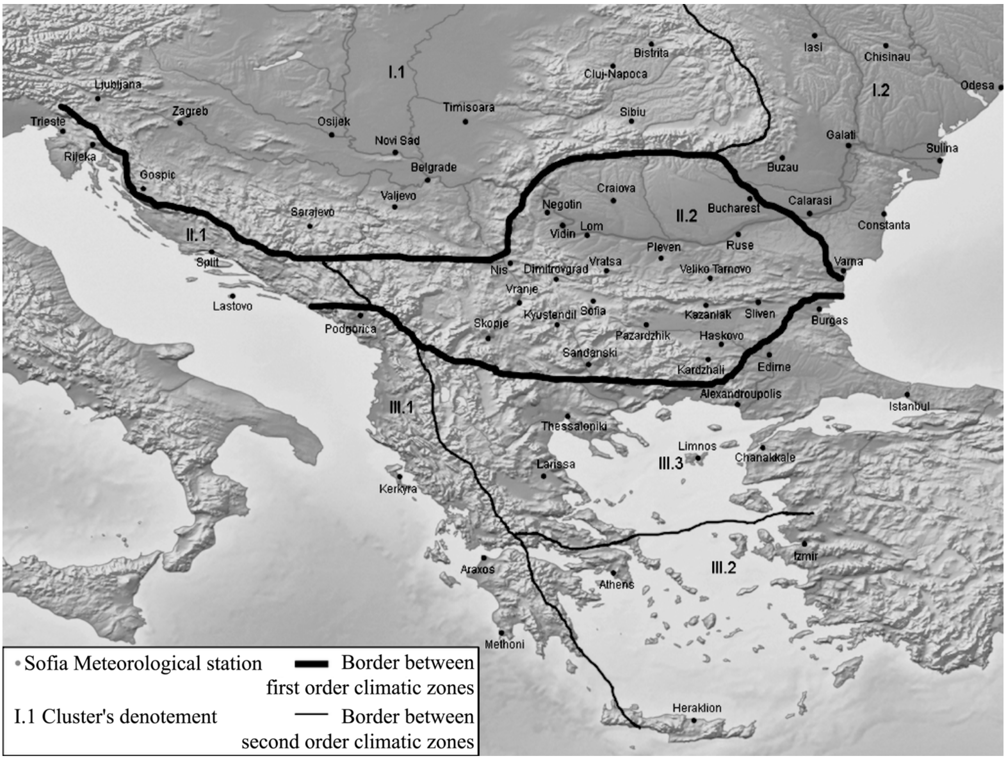

Figure 2 Regionalization of the Balkan Peninsula for the sub-period 1950–1986. Cluster I.1–temperate, oceanic climate; Cluster I.2–temperate, transitional continental-oceanic climate; Cluster II.1–transitional subtropical-temperate, transitional oceanic-continental climate; Cluster II.2–transitional subtropical-temperate, transitional oceanic-continental climate; Cluster III.1–subtropical, transitional oceanic-continental climate; Cluster III.2–subtropical, transitional continental-oceanic climate; Cluster III.3–subtropical, transitional continental-oceanic climate

3.1.1 Cluster I.1

Cluster I.1 in Figure 2 has a temperate oceanic climate. It includes stations Ljubljana, Zagreb, Gospic, Osijek, Sarajevo, Novi Sad, Valjevo, Belgrade, Timisoara, Cluj, Sibiu and Bistrita. There is an oceanic influence in the following periods–the region is under the influence of the Icelandic Low in March and April, from May to September it is under the influence of the Azores High and in November and December it is again under the influence of the Icelandic Low. Continental influence is associated with the Siberian High, which determines the air masses over this zone in January, February and October. The Siberian

High and the Icelandic Low bring air masses from temperate latitudes. On the other hand, there is a difference between positions of the Azores High either to the north or to the south of a given area. In this case, it is to the south of the region, leading again to a transport of air masses from temperate latitudes. Therefore, this zone (cluster) belongs to temperate climate. According to climatic regionalization of Romania (Posea, 2006) the southern part of this cluster has a transitional temperate to subtropical climate and the northern part (north of Timisoara) has a temperate oceanic climate. According to climatic regionalization of Serbia (Rakićević, 1980) this cluster includes two main climatic regions–temperate oceanic and temperate continental. According to climatic regionalization of Croatia (Šegota and Filipčić, 2003), which is based on Köppen classification, this cluster belongs to temperate humid climate with warm summer. According to climatic regionalization of Bosnia and Herzegovina (Alibegovic-Grbic, 2009) this cluster covers the region with temperate continental climate. According to climatic regionalization of Slovenia (Ogrin, 1996; Ogrin, 2004) this cluster belongs to temperate continental climate. It could be seen that there are different views on the type of climate of a certain territory in the different countries. The prevailing opinion is that the climate is temperate.

3.1.2 Cluster I.2

Cluster I.2 in Figure 2 has temperate transitional continental-oceanic climate. It includes stations Iasi, Chisinau, Odessa, Buzau, Galati, Sulina, Calarasi, Constanta and Varna. It should be mentioned that delineation of the borders of different clusters is somewhat arbitrary, due to the existing database. In this case as well as for the next sub-period (1987–2012) the border between this cluster and cluster II.2 runs generally along the line Bucharest-Calarasi. Also borders at the ends of the figure should be taken as contingent, because there are not enough stations in these areas. Oceanic influence in this zone is felt in April and May (the Icelandic Low), and in May and September (the Azores High). Continental influence prevails in the rest of the year–the Siberian High (January–March and October–November) and the East-European Low (June to August). In May and September the Azores High is located to the south of the region, while the other permanent or seasonal baric centers are associated only with air masses from temperate latitudes. That is why the zone belongs to temperate climate. According to previous climatic divisions of Bulgaria (Dimitrov, 1968; Sabev and Stanev, 1963; Stanev *et al*., 1991; Topliisky, 2006; Velev, 1990) this cluster covers territories with Pontic (subtropical), transitional to temperate continental and temperate continental climate. According to climatic division of Romania (Posea, 2006) this cluster includes territories with Pontic and arid (continental) temperate climate.

3.1.3 Cluster II.1

Cluster II.1 in Figure 2 has transitional subtropical to temperate and transitional oceanic-continental climate. It includes stations Trieste, Rijeka, Split and Lastovo. Oceanic influence in the region is realized by the Icelandic Low (February–April and November–December) and the Azores High (May–June and September). Continental influence prevails in January and October (the Siberian High), and in July and August (north-west extension of the monsoonal low). In May, June and September the studied area is located to the north of the Azores High and it could be assumed that it is mainly under the influence of air masses from temperate latitudes. On the other hand, north-west extension of the monsoonal low is associated with tropical air masses, i.e., within the year there are two months with tropical air masses. That is why this zone belongs to transitional subtropical to temperate climate. Basically, the area of clusters II.1 and II.2 could be considered as a very thick border between subtropical and temperate climates, because sharp boundaries are very rare in nature. According to climatic classification (after Köppen) of Croatia (Šegota and Filipčić, 2003), this cluster covers areas with Mediterranean climate with warm or hot summer. According to climatic regionalization of Slovenia (Ogrin, 1996; Ogrin, 2004) this cluster includes territories with coastal transitional to Mediterranean climate.

3.1.4 Cluster II.2

Cluster II.2 in Figure 2 has transitional subtropical to temperate and transitional oceanic-continental climate. It includes the following stations: Nis, Skopje, Vranje, Dimitrovgrad, Kyustendil, Negotin, Vidin, Lom, Craiova, Vratsa, Sofia, Sandanski, Pleven, Pazardzhik, Bucharest, Ruse, Veliko Tarnovo, Kazanlak, Haskovo, Kardzhali and Sliven. This is the main part of the territory of Bulgaria with the most stations. Oceanic influence in the area is associated with the Icelandic Low (March–April and December) and the Azores High (May–June and September). Continental influence is connected with the north-west extension of the monsoonal low (July–August) and the Siberian High (January–February and October–November). It could be accepted that the area is situated to the north of the Azores High in May, June and September, so it is under the influence of air masses from temperate latitudes. There are tropical air masses only in July and August (north-west extension of the monsoonal low). Therefore, the area belongs to transitional subtropical to temperate climate. According to climatic regionalization of Romania (Posea, 2006) this cluster includes regions with transitional temperate to subtropical or temperate dry (continental) climate. According to climatic divisions of Bulgaria (Dimitrov, 1968; Sabev and Stanev, 1963; Stanev *et al.*, 1991; Topliisky, 2006; Velev, 1990) this cluster covers regions with temperate continental, transitional temperate to subtropical and subtropical climate. According to climatic regionalization of Serbia (Rakićević, 1980) this cluster is characterized by areas with temperate continental and transitional from temperate to subtropical climate. According to climatic regionalization of Macedonia (Zikov, 1995) this cluster covers areas with temperate continental and transitional temperate to subtropical climate. It could be seen that in all classifications this cluster is transitional from temperate to subtropical climate.

3.1.5 Cluster III.1

Cluster III.1 in Figure 2 has subtropical, transitional oceanic-continental climate. It includes stations Podgorica, Kerkyra, Araxos and Methoni. Oceanic influence comes with the Icelandic Low (December–April) and with the Azores High (May–June). Continental influence is associated with the north-west extension of the monsoonal low (July–September) and the Siberian High (October–November). During three months of the year (July–September) the area is under the influence of tropical air masses. In June, it's in the southern periphery of the Azores High, which also leads to a dominance of tropical air masses. Therefore, this area belongs to subtropical climate. Climatic divisions of the three countries, which belong to studied region – Montenegro (Prvi nacionalni izvještaj Crne Gore o klimatskim promjenama prema okvirnoj Konvenciji Ujedinjenih nacija o klimatskim promjenama 2010), Albania (Merkoci *et al*., 2010) and Greece (Kokkini *et al*., 2004) – show that it has a Mediterranean (subtropical) climate.

3.1.6 Cluster III.2

Cluster III.2 in Figure 2 has subtropical, transitional continental-oceanic climate. It includes stations Athens, Heraklion and Izmir. Its northern border towards Asia Minor is quite arbitrary because of the small quantity of stations there. It is possible that it runs in somewhat northern direction. The Icelandic Low brings oceanic influence in the area. It dominates in the period from December to April. Continental influence is associated with the north-west extension of the monsoonal low (May–October) and the Siberian High (November). This is a typical subtropical climate in which six months of the year are dominated by tropical air masses, while the other six months are dominated by air masses from temperate latitudes. Climatic divisions of both countries, which belong to this cluster – Greece (Kokkini *et al*., 2004) and Turkey (Iyigun *et al*., 2013; Unal *et al*., 2003) – show that it has a Mediterranean (subtropical) climate.

3.1.7 Cluster III.3

Cluster III.3 in Figure 2 has subtropical, transitional continental-oceanic climate. It includes stations Thessaloniki, Larissa, Limnos, Alexandroupolis, Burgas, Edirne, Çanakkale and Istanbul. Oceanic influence is associated with the Icelandic Low (April and December) and the Azores High (May and September). Continental influence is realized by the Siberian High (January–March and October–November) and the north-west extension of the monsoonal low (June–August). The latter determines the presence of tropical air masses in summer. In May, this zone remains in the southern periphery of the Azores High, which also leads to a transport of tropical air masses. That is why this cluster belongs to subtropical climate. According to climatic divisions of the three countries included in this cluster– Bulgaria (Dimitrov, 1968; Sabev and Stanev, 1963; Stanev *et al*., 1991; Topliisky, 2006; Velev, 1990), Greece (Kokkini *et al*., 2004) and Turkey (Iyigun *et al*., 2013; Unal *et al*., 2003) –it has a subtropical climate.

3.2 Sub-period 1987–2012

Results of cluster analysis and regionalization for the sub-period 1987–2012 are shown in Figure 3. This sub-period is characterized by above the norm air temperatures.

Figure 4 shows that there are certain changes in comparison with the first sub-period, both in terms of the borders and extent of individual clusters.

3.2.1 Cluster I.1

Cluster I.1 in Figure 3 has oceanic, temperate climate. Its extent has shrunk compared to the previous sub-period (Figure 4) and includes stations Ljubljana, Zagreb, Gospic, Osijek, Sarajevo, Novi Sad, Valjevo, Belgrade and Timisoara. Oceanic influence is associated with the Azores High (January–February, May–September) and the Icelandic Low (March–April, October–November). There is a continental influence of the Siberian High only in December. The main changes in intra-annual course of SLP are shown in Figure 5a.

A typical for this cluster station was selected – Novi Sad. It could be seen that there is a serious increase of SLP in the period December–March. The causes are different. There is a

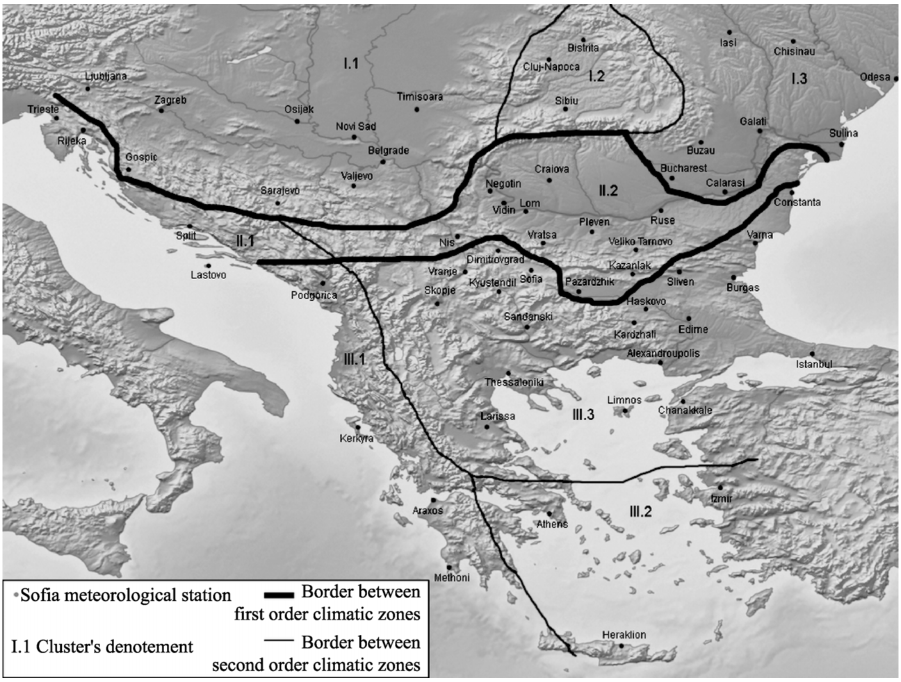

Figure 3 Regionalization of the Balkan Peninsula for the sub-period 1987–2012. Cluster I.1–temperate, oceanic climate; Cluster I.2–temperate, oceanic climate; Cluster I.3– temperate, transitional continental-oceanic climate; Cluster II.1–transitional subtropical-temperate, transitional oceanic-continental climate; Cluster II.2–transitional subtropical-temperate, transitional oceanic-continental climate; Cluster III.1–subtropical, transitional continental-oceanic climate; Cluster III.2–subtropical, transitional continental-oceanic climate; Cluster III.3–subtropical, transitional continental-oceanic climate

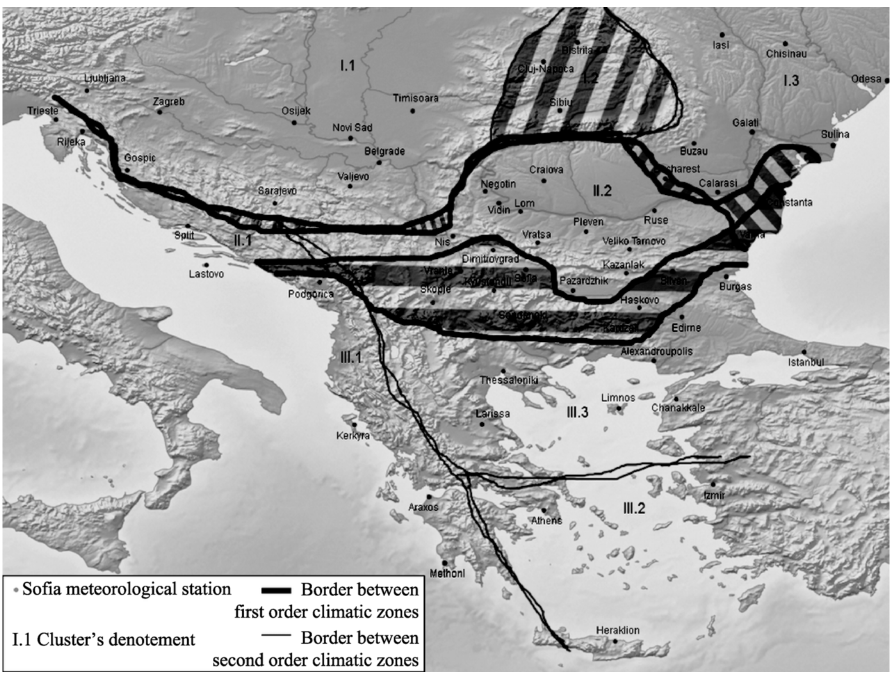

Figure 4 Spatial changes of cluster boundaries between the sub-periods 1950–1986 and 1987–2012. Areas with changes are hatched.

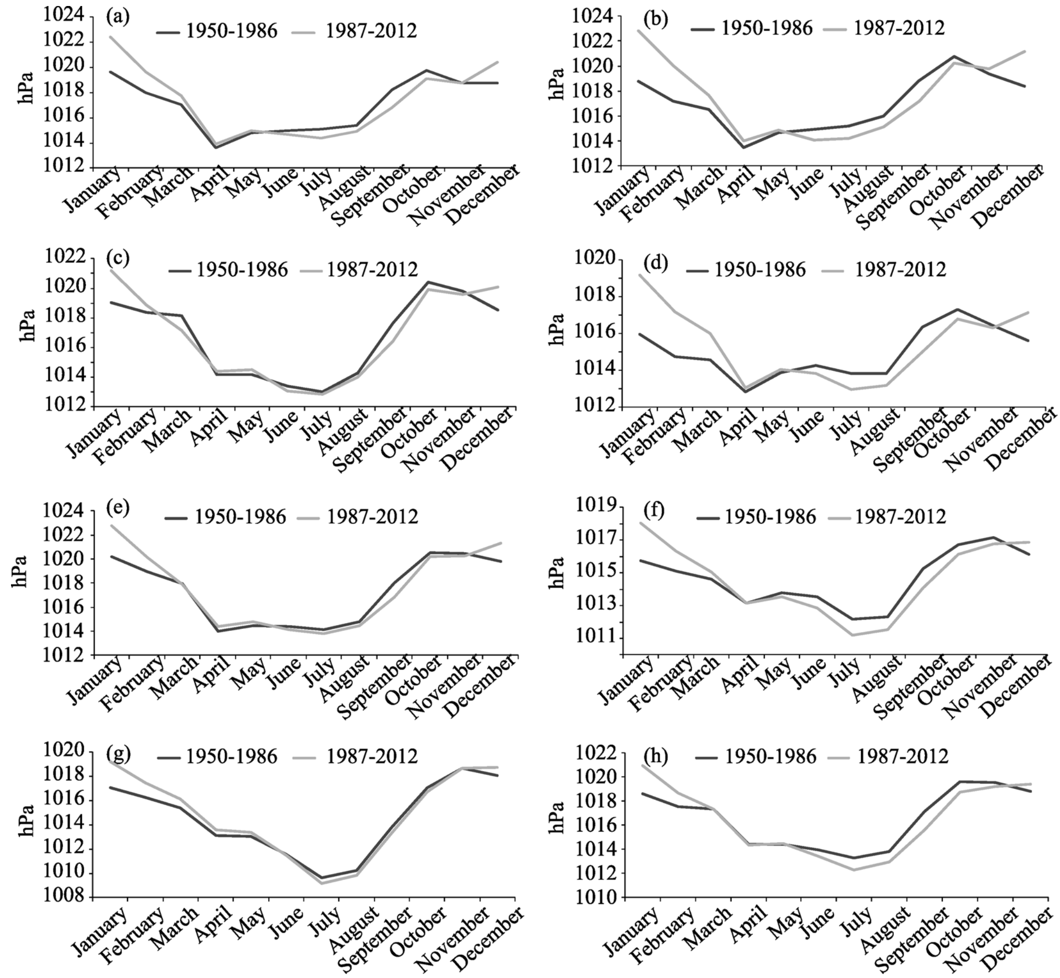

Figure 5 (a) Intra-annual SLP course at station Novi Sad for the two sub-periods; (b) Intra-annual SLP course at station Bistrita for the two sub-periods; (c) Intra-annual SLP course at station Chisinau for the two sub-periods; (d) Intra-annual SLP course at station Split for the two sub-periods; (e) Intra-annual SLP course at station Lom for the two sub-periods; (f) Intra-annual SLP course at station Araxos for the two sub-periods; (g) Intra-annual SLP course at station Izmir for the two sub-periods; (h) Intra-annual SLP course at station Alexandroupolis for the two sub-periods

shift from an influence of the Icelandic Low towards an influence of the Siberian High in December. While in January and February the Siberian High is replaced by the Azores High, which in this region leads to higher values of SLP. It could also be seen that the influence of the Azores High in the period from June to September weakens on the expense of (probably) a strengthening of the influence of the north-west extension of the monsoonal low. There is a replacement of the Siberian High with the Icelandic Low in October, which also leads to a decrease of the values of SLP. All in all the trends in this climatic zone show strengthening of oceanic and subtropical influences.

3.2.2 Cluster I.2

Figures 3 and 4 show that during this sub-period a new cluster appears – I.2. It has oceanic, temperate climate and includes stations Cluj, Sibiu and Bistrita. The feature that distinguishes it from the previous cluster is stronger continental influence. It is associated with the Siberian High in the period from October to December. Oceanic influence is present in January–February and May–September (the Azores High), and in March–April (the Icelandic Low). A typical station is selected to show the changes in intra-annual course of SLP – Bistrita (Figure 5b).

Trends and causes are the same as in the previous area – an increase of SLP in the period from December to March and a decrease in the period from June to September. Comparison of the ratio oceanic/continental influence (9/3 months) between both sub-periods shows that there is no change, but there is a certain redistribution of these influences over the year. A strengthening of subtropical influence is also evident here.

3.2.3 Cluster I.3

Cluster I.3 in Figure 3 corresponds to cluster I.2 in Figure 2. It has continental-oceanic, temperate climate and includes stations Iasi, Chisinau, Odessa, Buzau, Bucharest, Calarasi, Galati and Sulina. It should be pointed out again that the border between this cluster and cluster II.2 runs along the line Bucharest-Calarasi. According to Figure 4 there is a slight shift of this border in southwest direction. On the other hand, the area between the Danube and the Black Sea belongs now to two other clusters (II.2 and III.3). Continental influence in cluster I.3 is realized by the East European Low (May–August), the Siberian High (October–December) and in some years by the north-west extension of the monsoonal low (June–August). Oceanic influence comes with the Azores High (January–February and September) and the Icelandic Low (March–April). Station, which was selected to show the changes in intra-annual course of SLP in this zone, is Chisinau (Figure 5c).

There is an increase of SLP in the period from December to February. This is due to the transition from an influence of the Icelandic Low to an influence of the Siberian High in December. There is a transition from influence of the Siberian High to influence of the Azores High in January and February, which also leads to higher SLP values. In the rest of the year no significant changes occur. The overall trend is towards more oceanic climate in the zone (5 months in this sub-period compared to 4 months in the previous). Also a strengthening of the influence of subtropical climate could be observed here.

3.2.4 Cluster II.1

Cluster II.1 in Figure 3 has transitional oceanic-continental and transitional subtropical to temperate climate. According to Figure 4 its extent widened somewhat along its northern border and it includes stations Trieste, Rijeka, Split and Lastovo. Oceanic influence is associated with the Azores High (January, May and September) and the Icelandic Low (February–April, October–November). There is a continental influence in June–August (north-west extension of the monsoonal low) and December (the Siberian High). The station, which was selected to illustrate the changes in intra-annual course of SLP, is Split (Figure 5d).

It could be seen that there is a significant increase of SLP in the period December–March. The causes are the same as for the other clusters, with a difference that there is a strengthening of the influence of the Azores High in February and March, but these months still remain under the dominant influence of the Icelandic Low. There is a decrease of SLP in the period from June to September, due to the growing influence of the north-west extension of the monsoonal low. In terms of the ratio oceanic/continental influence no differences with the previous sub-period could be seen, although there is certain redistribution within the year. However, the strengthening and expansion of influence of tropical air masses in summer is evident.

3.2.5 Cluster II.2

Cluster II.2 in Figure 3 has transitional oceanic-continental and transitional subtropical to temperate climate and includes stations Nis, Negotin, Vidin, Craiova, Lom, Vratsa, Pleven, Pazardzhik, Veliko Tarnovo, Kazanlak and Ruse. Oceanic influence is associated with the Azores High (January–February, May and September) and the Icelandic Low (March–April). There is a continental influence in the other six months of the year–June to August (north-west extension of the monsoonal low) and October–December (the Siberian High). Figure 4 shows that this cluster has widened northwards in the areas around Nis and along the Black Sea coast and has shrunk in southwest direction in the area around Bucharest. A typical station for this area, which shows changes in intra-annual course of SLP, is Lom (Figure 5e).

It reveals that there is a significant increase of SLP in the period from December to February. The causes have already been discussed above. There are no changes in the ratio oceanic/continental influence (6/6 months), but there is certain redistribution within the year. There is a tendency towards strengthening and expanding of the influence of tropical air masses in the area. This fact can be further illustrated by a few numerical indicators. Table 1 shows trends of calculated for Bulgaria zonal index.

Table 1 Trends (per decade) of the zonal index over Bulgaria for the period 1950– 2012. Statistically significant numbers are bolded.

	Zonal index
January	0.05
February	–0.01
March	0.06
April	0.03
May	–0.01
June	–0.03
July	–0.04
August	**–0.06**
September	–0.04
October	0.02
November	0.05
December	0

Table 2 shows relationship between this index and the EA pattern for the two studied sub-periods.

Table 2 Spearman correlation between EA index and zonal index over Bulgaria for different periods. Statistically significant numbers are bolded.

	1950–1986	1987–2012
	EA-Zonal index	EA-Zonal index
January	0.20	0.21
February	**0.34**	**0.42**
March	–0.06	0.25
April	**0.54**	0.23
May	0.27	–0.29
June	0.21	–0.07
July	–0.10	**–0.48**
August	–0.12	–0.37
September	–0.1	**–0.45**
October	0.18	0.13
November	**0.37**	**0.46**
December	0.11	0.31

It is known that EA pattern represents roughly the Azores High. Its positive values indicate a strong development of this baric center and vice versa. Examination of the relationship between EA pattern and zonal index over Bulgaria in 1950–1986 sub-period shows that in July, August and September the values are negative. This means that a strong development of the Azores High is associated with eastern transport of air masses over Bulgaria. This in turn means that the Azores High is situated to the north of Bulgaria and the country is dominated by tropical air masses in these months. The sub-period 1987–2012 in Table 2 shows that negative values occur also in May and June, and in the remaining three months (July to September) the values become statistically significant. This means that there is a tendency of expansion and strengthening of the influence of tropical air masses. This trend is confirmed by the values in Table 1, where there is a strengthening of the eastern transport of air masses at the expense of the western in the period from May to September. The combination of these two indices gives another opportunity for a relatively accurate numerical evaluation of the location of air masses over a certain territory.

3.2.6 Cluster III.1

Cluster III.1 in Figure 3 has transitional continental-oceanic, subtropical climate and includes stations Podgorica, Kerkyra, Araxos and Methoni. Oceanic influence comes with the Azores High (January, May) and the Icelandic Low (February–April). There is a continental influence in June–September (north-west extension of the monsoonal low), and October–December (the Siberian High). Figure 4 shows that its northern border has moved northwards thus widening its extent. The station, which illustrates changes in intra-annual course of SLP, is Araxos (Figure 5f).

It could be seen that there is a well marked increase of SLP in the period from December to March and decrease in the period from June to September. The causes have been already mentioned above (cluster II.1). The main trends observed in this area are strengthening of continental influence (from 5 to 7 months of the year) and a longer dominance of tropical air masses. Both trends are related to the increased influence of the north-west extension of the monsoonal low.

3.2.7 Cluster III.2

Cluster III.2 in Figure 3 has transitional continental-oceanic, subtropical climate and includes stations Athens, Heraklion and Izmir. Oceanic influence is associated with the Azores High (January) and the Icelandic Low (February–April). There is a continental influence in May–October (north-west extension of the monsoonal low) and November–December (the Siberian High). The station, which shows changes in intra-annual course of SLP in this zone, is Izmir (Figure 5g).

There are higher values of SLP in the period December–March. The causes are the same as in the other northern areas. This leads to a greater continental influence–from 7 to 8 months a year. There is no change in the extent and degree of influence of tropical air masses.

3.2.8 Cluster III.3

Cluster III.3 in Figure 3 has transitional continental-oceanic, subtropical climate and includes stations Vranje, Skopje, Dimitrovgrad, Kyustendil, Sofia, Sandanski, Thessaloniki, Larissa, Constanta, Varna, Burgas, Sliven, Haskovo, Kardzhali, Edirne, Alexandroupolis, Limnos, Canakkale and Istanbul. It should be pointed out that this is the area that widens the most its territorial coverage (Figure 4) compared to the previous sub-period, mostly because of shifting to the north of its northern border. Thus large parts of south-western, southern and northeastern Bulgaria are included in this zone. The biggest change could be observed in the region of Varna–Constanta, which goes directly from temperate to subtropical climate.

Oceanic influence is associated with the Azores High (January–February and May) and the Icelandic Low (March–April). There is a continental influence in June–September (north-west extension of the monsoonal low), and October–December (the Siberian High). The station, which shows changes in intra-annual course of SLP in the area, is Alexandroupolis (Figure 5h).

It could be seen that the characteristic SLP increase in the period December–February and the decrease in the period from June to October also exist here. The causes have been already mentioned earlier. There is a strengthening of the oceanic influence (from 4 to 5 months) due to the replacement of the Siberian with the Azores High in January and February, i.e., oceanic influence is increasing mainly in winter. On the other hand the influence of the north-west extension of the monsoonal low strengthens and expands, which leads to an increased transport of tropical air masses. This process is particularly pronounced in the northern periphery of the zone.

The main problem with agglomerative CA (Badr *et al*., 2015) is the noise of the input data. In this regard, it is essential to select the appropriate metrics – distance measures or correlation coefficients, and methods–single linkage, complete linkage, centroid, Ward's minimum variance or average distance (Iyigun *et al*., 2013; Unal *et al*., 2003). The input data in this study is SLP, which is an element that changes relatively smoothly spatially. In this context, the distance measures would provide a more detailed picture of the spatial distribution, because this approach is more sensitive to input data. On the other hand, as already mentioned above, the input data are loaded with certain noise, which is the case with SLP data. That is why the correlation coefficient was used as the primary metrics in this study. According to Kalkstein *et al*. (1987) the best method for climatological studies is average distance. It showed the best results (according to the basic principles of regionalization) in comparison with the other main methods and was therefore selected for use in this study. Thus, higher rank units within the Balkan Peninsula were differentiated and the use of 61 stations is sufficient to define these units. However, there is some uncertainty along the borders of the studied domain, mostly along the northern border, where the Balkan Peninsula transitions into continental Europe, as well as along the coast of Asia Minor. The usage of some additional stations in these regions could change somewhat the external boundaries of the clusters, but climate regionalization of the Balkan Peninsula will remain the same. This is due to the fact that as with any objective method of regionalization, there is a certain element of subjectivity in the determination of boundaries in accordance with generally accepted principles for regionalization (Zheng *et al*., 2010; Dezfuli, 2011).

Climate zones of the Earth are based on three main factors–solar radiation, atmospheric circulation and local physical-geographical conditions (surface type, relief forms, etc.). The solar radiation is a factor of first order, atmospheric circulation is a factor of second order and local physical-geographical conditions are a factor of third order. Two basic climatic elements–air temperature and precipitation–are used in virtually all climate regionalizations, which include areas of the Balkan Peninsula. It is natural for empirical regionalization such as that of Croatia (Šegota and Filipčić, 2003), but these two elements are also used in genetic regionalizations (Posea, 2006; Rakićević, 1980; Alibegovic-Grbic, 2009; Ogrin, 2004; Dimitrov, 1968; Sabev and Stanev, 1963; Stanev *et al*., 1991; Topliisky, 2006; Velev, 1990; Zikov, 1995, etc.) in order to represent the two leading factors–radiation (through air temperature) and circulation (through precipitation), namely, the genetic regionalizations also employ quantitative (measurable) characteristics. However, the main drawback of these two climatic elements is that they are influenced largely by local physiogeographical conditions. A typical example is meteorological stations located on opposite banks of the Danube River. The stations, located on the southern (higher) bank on the Bulgarian side have average annual air temperatures which are higher by 0.5°C to 0.8°C compared to air temperatures of the stations located on the Romanian (lower) bank. This is due to the fact that during the winter months, the cold air is retained in the lower parts thus lowering the corresponding average monthly temperatures, which also lowers average annual air temperature. In an objective regionalization (e.g. cluster analysis) stations on opposite banks of the river would belong to different spatial units, which is obviously not right. In other words, air temperature does not represent precisely enough the radiation factor and precipitation does not represent precisely enough the circulation factor. Also, the use of two or more, different in physical nature, climatic elements requires a certain standardization through various statistical methods. Different climatic elements have different variations which can affect CA, giving more weight to one or another variable (Iyigun *et al.*, 2013). Some information can be lost in preliminary statistical processing, which is definitely not beneficial for the climate regionalization. All this causes the observed differences in climate regionalizations of the countries of the Balkan Peninsula regardless of the fact that authors use regionalizations based on same principles or regionalizations based on objective methods. On the other hand, SLP is practically not influenced by local physical-geographical conditions and describes very well the circulation factor. Also it is a climatic element, which is measured at a sufficient number of meteorological stations. In this sense SLP is extremely suitable as a numerical criterion for climate regionalization of genetic type – air masses with certain origin. Air temperatures and precipitation can be used to define spatial units of third order (defined by local physiogeographical conditions). The proposed method can be used for objective regionalization of other parts of the world, especially in regions that are located on the border between two major climate zones. Also, the method facilitates tracking temporal changes of the boundaries of the different climatic territorial units. This is especially important for agriculture and water sector, because revealed trends will allow for a better planning, taking into account all potential risks. For example, the shift to the north of the northern border of the subtropical zone in the Balkan Peninsula means, besides the increase of average air temperatures, a redistribution of precipitation amounts during the year, which will require certain adaptation measures.

4 Conclusions

This genetic climatic regionalization of the Balkan Peninsula largely unifies climatic regionalizations of the different countries. The usage of intra-annual course of SLP is a good basis for numerical parameterization of a classification of genetic type. Thus, many of the existing in this type of classification problems are addressed. Cluster analysis allows for an objective grouping of studied stations. But a subjective control is still necessary due to the fact that collected data are not perfect and despite the serious homogenization they still may contain errors or deviations. In this case, the use of more insensitive approach to measurement of the intervals, which is Pearson correlation, appears most appropriate. The use of different indices that characterize regional or parts of global atmospheric circulation could also be helpful in climatic regionalization of a certain territory.

Another major conclusion of this study is that climatic zones in the Balkan Peninsula should not be defined unambiguously as continental or oceanic. This is done in most of the current climatic regionalizations of the countries, which leads to many differences and discrepancies. In these regionalizations eastern, southeastern and northwestern (Slovenia) parts of the peninsula are defined as continental and central north (Serbia) part–as oceanic. The regionalization, done in this research, demonstrates that the climate of the entire Balkan Peninsula is transitional oceanic-continental. It also could be concluded that the peninsula climate is transitional between subtropical and temperate in south-north direction.

Climate system is dynamic in time, which leads to certain differences in the spatial extent of different climate zones. Several major changes in atmospheric circulation over the Balkan Peninsula, which influence its climatic regionalization, have happened over the period 1950–2012. There is a serious increase of the influence of the Azores High in the period January–March, which leads to an increase of SLP and enhances oceanic influence. These air masses in the cold half of the year have also higher than normal air temperatures. There is an increase of the influence of the north-west extension of the monsoonal low in the period from June to September. This leads to more continental climate, but also to more tropical air masses over the Balkan Peninsula. Accordingly, the extent of subtropical climate widens in northern direction. There is an increase of the influence of the Siberian High in the period from October to December. This influence covers central and eastern part of the peninsula in October and November, and it reaches western parts in December. Thus, the climate becomes more continental. These air masses have lower than normal air temperatures and originate from temperate latitudes, but because of the fact that this process occurs in the cold half of the year it does not affect the extent of subtropical or temperate climates.

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