



An example of principal component analysis application on climate change assessment

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Abstract

Climate change assessment is usually based upon air temperature and precipitation changes on an annual and seasonal basis, but there are more levels to their significance as presented by parameters derived from these two basic parameters. In order to define their relevance for climate changes, the principal component analysis (PCA) was performed. In this case, ten meteorological parameters and climate change indicators were defined for two meteorological stations located in geographically completely opposite parts of the country; station Osijek is in continental region of Croatia, and Dubrovnik station is located in the Mediterranean region. Analyses were done for the period 1985–2016 on an annual and seasonal basis. All defined indicators present basic climate change characteristics on annual and seasonal basis as follows: precipitation sum, mean air temperature, air temperature sum, standard deviation of daily air temperature, maximum daily air temperature, maximum daily precipitation, number of days with precipitation > 30 mm, number of days with no precipitation, 1-month standardized precipitation index, and aridity index. In the first step, it was applied on the set of linear regression coefficients defined for 10 climate change indicators. During the second step, PCA was applied on the computed Mann–Kendall test statistic, Z_{MK} , in order to determine the existence of significant temporal tendencies in the indicator values. The provided research proves PCA is a very useful tool for implementing this approach, particularly in the Mediterranean region which shows high sensitivity to many variables important for climate characterization.

Keywords Climate change indicators · Principal component analysis

1 Introduction

Analysis of climate change impacts using climatological, meteorological, and hydrological maps of Europe has been conducted over the last few decades. Many data sets observed from hundreds of weather stations throughout Europe have been analyzed and dozens of climate change scenario simulations have been developed. These studies are related to the main climate change characteristics of different time scales—extremes of hydrological events (droughts, torrents, and floods), increasing air temperature (warming), and a

change in the precipitation pattern (increasing/decreasing). There are many studies of the spatial variability in the sign, magnitude, and seasonality of the trends in precipitation and temperature and extremes throughout Europe focused on individual European countries, regions, or sub-regions (Moberg et al. 2006; Kyselý 2009). The regional differences are caused by geographical position and circulation patterns and by the influence of local factors such as orography and distance from the sea (Gajić-Čapka et al. 2015). The main changes are in air temperature patterns and precipitation regimes, which consequently have a great impact on the water budget and water management of any area. Air temperature is increasing nearly throughout the world. However, during recent years, there is evidence that extreme rainfall intensity is increasing at a global scale. Research now indicates that the greatest increases are likely to occur during short-duration storms of less than 1 day, potentially leading to an increase in the magnitude and frequency of flash floods (Westra et al. 2014).

Focusing on Europe, there is a difference in air temperature and precipitation behavior between its northern and southern

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parts related to climatic features, altitude, and other regional characteristics. Analysis of century-long daily temperature for 75 stations mostly representing Europe west of 20° E shows a warming trend for all temperature indices during winter and summer. In addition, winter precipitation totals, averaged over 121 European stations north of 40° N, have significantly increased (approximately 12%/100 years) (Moberg et al. 2006).

For example, in northern Europe (Finland), analysis of long-term daily precipitation patterns at three spatially distinct monitoring stations in southern, central, and northern Finland found spatial differences and statistically significant trends for some daily precipitation indices during the past century (Irannezhad et al. 2016). Analysis of climatic characteristics of Alpine Europe (Austria and Switzerland) shows that the dominant climate change process is drying in Austria and warming in Switzerland, but large areas are characterized by a cold and wet climate in the Central Eastern Alps that did undergo any climate change during the twentieth century (Ács et al. 2018). Analysis of climate change indices in Central Europe (Czech Republic) partly supports a prevailing global positive trend in precipitation extremes over mid-latitude land areas of the Northern Hemisphere during winter. However, the trends in winter indices of precipitation extremes may indicate that the pattern of changes is more complex and less coherent in Eastern than in Western Europe (Kysely 2009).

In the case of Croatia's neighboring country, Hungary, the climate remained unchanged over 76.7% of Hungarian territory (practically the entire Great Hungarian Plain) but the main noted climate change process is drying (Breuer et al. 2017). In a study of air temperature and precipitation trends in Serbia, another neighboring country, increasing trends were found in both annual and seasonal minimum and maximum air temperature series. In addition, no significant trends were detected in summer and winter precipitation series (Gocić and Trajković 2013).

Research of air temperature observed at 67 Western Balkans weather stations during the last 48 (from 1961 to 2008) and 158 (from 1851 to 2008) years shows that, in the analyzed Balkans region, warming started during the period between 1987 and 1997, mostly in 1988. Differences in the average mean annual air temperature before and after warming are approximately 0.807 °C (Bonacci 2012). Investigation of the Mediterranean region, which is the most endangered area in Europe related to water availability in the future, by Philandras et al. (2011) showed that statistically significant (95% confidence level) negative trends in the annual precipitation occur in the majority of Mediterranean regions during the period 1901–2009, with the exception of northern Africa, southern Italy, and the western Iberian Peninsula, where slight but not significant positive trends are found. In addition, during the period 1951–1995 over the relatively large Mediterranean region, investigations have confirmed increasing torrential rainfalls in Italy and Spain but

no significant trends were found in Israel and Cyprus (Alpert et al. 2002). The study of 106 daily rainfall series (1955–1999) from stations in southern Portugal mostly shows positive trends of drought and desertification indicators and short-term precipitation intensities over the region during the obtained period, but there are no significant trends in wetness indices at the majority of the stations (Costa and Soares, 2009).

An Italian contribution to studies of global climatic change was completed through analysis of 110 years of temperature data for Florence including means and trends of annual and monthly temperatures. At a short time scale (20 years), climate change was found in minimum and average temperatures but not in maximum temperatures. At three time scales of short (20 years), medium (36–38 years), and long (55 years), the annual means of minimum, maximum, and average temperatures were significantly warmer during the latter than during the early part of the twentieth century (Kumar et al. 2005).

Results of Croatian scientists related to this subject indicate that there is a positive trend in the 25-year air temperature moving averages in Croatia, which is in agreement with the global climate warming trend. Precipitation moving averages show more significant irregular cyclic variations than the air temperature averages and only a slight negative linear trend (Pandžić et al. 2009). Positive mean annual temperature trends are evident from the beginning of the twentieth century and are increasingly expressed during the last 50 and particularly during the last 25 years. The greatest contribution to positive trends in annual values at the Adriatic coast occurred during the warm season, while, in the continental region, the warming was more pronounced during the cold season. Most of the 10 warmest years occurred during the last 10-year period (Zaninović 2010). According to Bonacci (2010), intensive warming started in 1988 in the continental (northern) region of Croatia and in 1992 in the Mediterranean region (southern part).

As indicated in this chapter, the data used in climate change analysis are air temperature and precipitation long-term series, but there were no investigations regarding cumulative impacts of different variables or their combination on climate change. This approach will be further developed using principal component analysis on an example of two representative Croatian meteorological stations.

Principal component analysis (PCA) usually is used for the representation of spatial cause–effect data. It can be applied in various fields of research, from social to natural sciences (Fulgosi 1984; Preisendorfer 1988). There are many examples of this method used in investigation of causal connections between spatial rainfall–runoff and rainfall–drought (Rao and Burke 1997). In addition, in the literature, the ability of PCA to describe regional characteristics and differences among low-flow regimes at a large number of hydrological stations has been demonstrated (Daigle et al. 2011).

Furthermore, it has been shown that PCA reduces the number of parameters to extract the most important factors in the analysis of surface and groundwater quality data or any other group of many parameters. Components that do not show correlation with any of the other components can be screened out of the analysis (Singh et al. 2009; Sharma et al. 2015; Othman et al. 2015). In this manner, the most important factors affecting water quality, hydrological, or other multi-parameter processes provide a much better estimation of the mutual relationship among the parameters and their evaluation (Loska and Wiechuła 2003; Guo et al. 2004; Parinet et al. 2004; Sahu et al. 2018). The theory and application of PCA was also examined in the context of meteorology and climatology on example of climatic pattern analysis on 3 and 7-day summer rain totals of 402 stations in the central USA (Richman and Lamb 1985; Richman 1986). In Croatia, PCA was applied on data of monthly precipitation obtained on 108 meteorological stations located in the area from Adriatic Sea to the Pannonian lowland in the period between 1961 and 1980. Using the loadings of the PCs, four homogeneous

precipitation sectors are determined and compared with those obtained by Koppen's scheme (Pandžić 1988). Previously, the PC analysis was also applied on mean monthly air temperatures obtained on the 108 meteorological stations in the same area and same period. The first three PCs are considered which described 99.6% of total temperature field variance. It is shown that the first PC is related to the mainland heat, the second one to the sea heat, and the third one to the atmospheric circulation (Pandžić 1986).

2 Study area

For the analysis of climate change indicators applying principal component analysis (PCA), data were taken from two Croatian meteorological stations in geographically completely opposite parts of the country (Fig. 1). Station Osijek is in Slavonia (Pannonian Valley of the Danube River Basin) in northeastern Croatia, near the Hungarian and Serbian border. The climate is continental, typical for Central Europe with hot

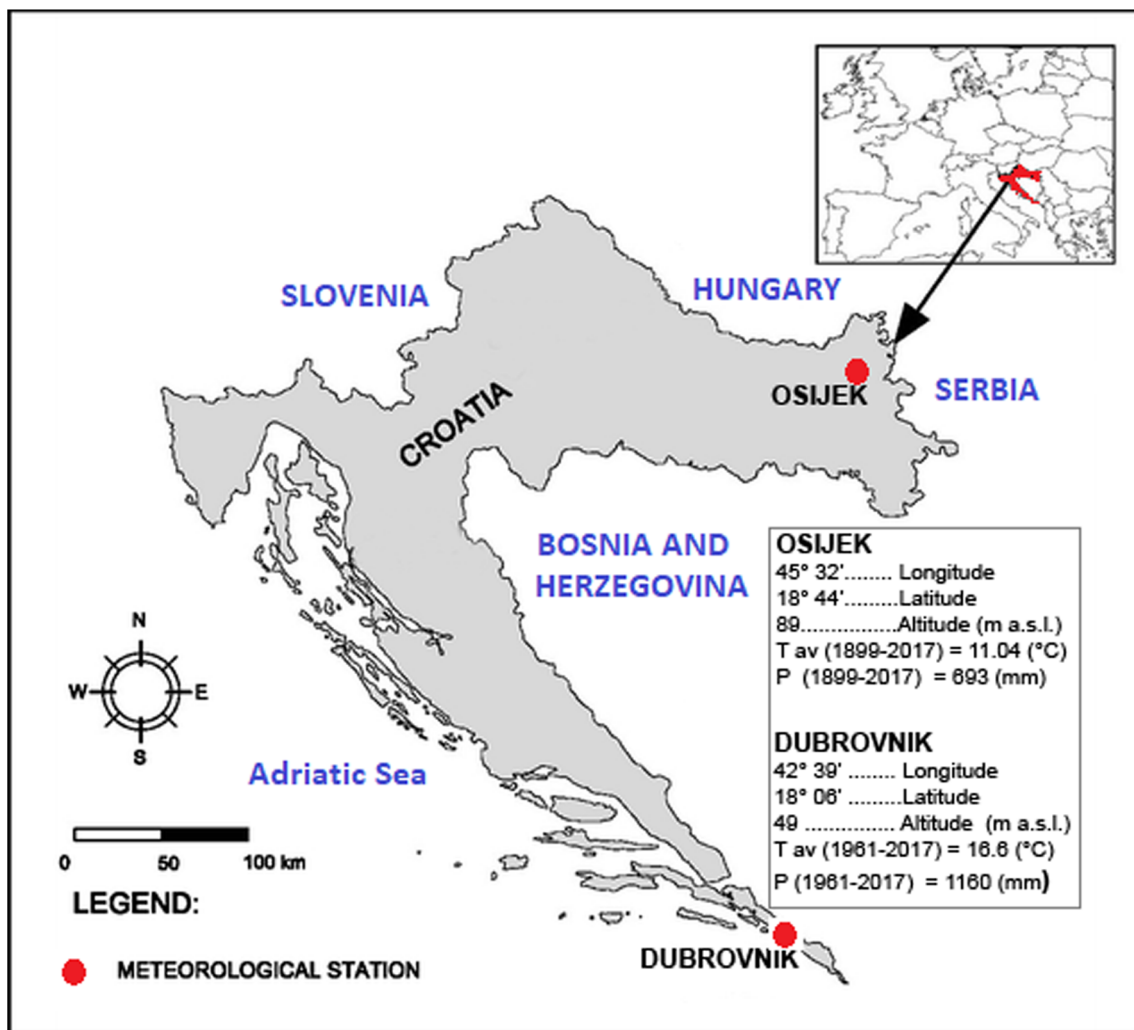


Fig. 1 Study area

summers and cold winters very often with snow cover. The rainiest months are May and June, and days with maximum daily precipitation amounts occur more often during summer. On an annual basis, a decreasing precipitation trend prevails. The analyzed period (1985–2016) has a mean annual precipitation of 681 mm which is 12 mm less than mean value of the longest available data series (1899–2017) (Fig. 1, Table 1). The continental region of Croatia is characterized by an increase in precipitation only during autumn, being statistically significant in the most eastern portion (12.4 mm/10 years) (Gajić-Čapka et al. 2015). The mean annual air temperature of the same period is 11.5 °C with an increase of nearly 0.5 °C compared with the longest available data series (Fig. 1, Table 1).

The southern, Mediterranean region of Croatia is represented by the Dubrovnik meteorological station, with the subtropical climate region characterized by the rainiest period occurring from November to May with large daily precipitation more often during the cold part of the year (Gajić-Čapka et al. 2015). The mean annual precipitation during the analyzed period (1985–2016) is 1108 mm which is 52 mm less than mean of the longest available data series (1961–2017) (Fig. 1, Table 2). The mean annual air temperature of the same period is 16.9 °C with an increase of nearly 0.3 °C compared with the longest available data series (Fig. 1, Table 2).

According to the “Sixth National Communication of the Republic of Croatia under the United Nations Framework Convention on Climate Change” (2013), greater warming, between 1.5 and 2 °C, is projected over the eastern and central parts of Croatia during winter and over central and southern Dalmatia during summer. The largest near-future change in seasonal precipitation is expected during autumn, with a decrease in precipitation over the larger part of Croatia. However, in Slavonia, precipitation is projected to increase between 2 and 12%, and more than 12% in the eastern part of the country (Slavonia) where the increase is statistically significant. A precipitation decrease of the same amplitude is projected for southern Croatia during spring.

Characteristics of these two representative meteorological stations in more detail are given in Tables 1 and 2.

The most important climate change effects are increasing air temperatures on an annual and/or seasonal basis and changes in the precipitation regime and frequency of extreme hydrological events. On the basis of air temperature and precipitation, it is possible to derive other climate change indicators.

Basic climatic characteristics of the representative stations are given in Figs. 2, 3 and 4 in more detail. Standardized precipitation index (SPI) is a standard measure of drought severity and is calculated on a monthly basis. Figure 2 shows similar dry and wet periods (1985–2016) with the most severe drought occurring during 2000, 2003, 2007, and 2012 in both the continental (red) and Mediterranean (blue) regions.

More precise insight of drought susceptibility can be done by aridity index which is a ratio between precipitation and potential evapotranspiration. Previous investigations done for the period 1971–2000 (Perčec Tadić et al. 2014) show that summer period in Osijek area belongs to semi-arid or dry sub-humid zone (with exception of June). Dubrovnik region is much warmer, and summer period is characterized as arid or semi-arid. The rest of the year has characteristics of a humid zone in both regions. Values of aridity index presented in Fig. 3 are calculated as ratio between monthly precipitation and monthly potential evapotranspiration calculated by Hargreaves equation (Hargreaves and Samani 1982; Trajković 2007). During the period 1985–2016, aridity index varies between 0 and 4 depending on season and consistent to previous investigation. Values of the standard deviations of daily air temperatures during the period 1985–2016 for Osijek and Dubrovnik stations show differences induced by geographical features. The standard deviations of daily air temperatures are much higher in the continental region (Osijek station) that is a characteristic of an inland region (Fig. 4).

The average number of days with daily precipitation greater than 30 mm also confirms the basic features of continental and Mediterranean climates. The most of heavy rainfalls occur during October, November, and December (Fig. 5a). However, both meteorological stations show a very similar pattern of days without precipitation during spring, autumn,

Table 1 Meteorological characteristics of Osijek station (1985–2016)

Osijek (1985–2016)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Air temperature												
Mean (°C)	0.4	1.9	6.6	12.1	17.1	20.3	22.3	21.6	16.8	11.6	6.0	1.5
Daily maximum (°C)	11.6	14.4	17.5	22.5	25.8	29.6	31.5	30.4	27.9	21.2	17.6	14.6
Year	2001	1989	2001	2003	2008	2013	2007	2012	2008	1993	1998	1989
Precipitation												
Mean (mm)	45.6	40.2	44.3	50.4	63.9	81.9	57.9	65.8	61.7	57.3	58.8	50.6
Daily maximum (mm)	39.3	31.6	33.2	28.8	84.5	107.2	56.7	73.4	81.0	53.3	37.9	32.2

Table 2 Meteorological characteristics of Dubrovnik station (1985–2016)

Dubrovnik (1985–2016)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Air temperature												
Mean (°C)	9.5	9.6	11.6	14.6	19.0	22.9	25.6	25.8	21.9	18.0	14.0	10.5
Daily maximum (°C)	15.9	19.7	19.0	23.1	32.9	31.2	32.9	33.4	28.6	26.5	23.3	18.4
Year	2010	1990	2001	2000	2009	2016	2007	2012	2011	2012	1992	2014
Precipitation												
Mean (mm)	111.5	107.8	103.6	88.0	69.9	54.1	30.9	48.9	87.8	128.0	146.1	132.2
Daily maximum (mm)	84.9	79.0	158.6	80.6	54.8	91.0	89.5	128.8	191.0	154.8	161.4	109.2

and winter. Only during summer extensive dry periods are more frequent in the Mediterranean region (Fig. 5b).

Standard deviations in air temperatures, monthly standardized precipitation index (1-month SPI), aridity index, maximum daily precipitation and air temperature, monthly number of days without precipitation and number of days with precipitation > 30 mm, mean and sum of monthly air temperatures, and precipitation sum calculated on an annual and seasonal basis were used in further analysis.

3 Principal component analysis

In this case, PCA was performed in two steps. The first was on the set of linear regression coefficients defined for 10 climate change indicators, and the second was on the set of Mann–Kendall statistics Z_{MK} . Ten meteorological parameters and climate change indicators were defined for two meteorological

stations, Osijek and Dubrovnik, during the period 1985–2016 on an annual and seasonal basis. They all indicated basic climate change characteristics as follows:

- Changes in air temperature and precipitation (increasing/decreasing)—annual and seasonal precipitation sum, mean annual and seasonal air temperature, and annual and seasonal air temperature sum, mean annual and seasonal aridity index (four indicators)
- Increasing variability of air temperature—standard deviation of daily air temperature calculated on annual and seasonal basis (one indicator)
- Frequency of extreme values (maximum/minimum values)—annual and seasonal maximum daily air temperature, annual and seasonal maximum daily precipitation, annual and seasonal number of days with precipitation > 30 mm, annual and seasonal number of days with no precipitation, and annual and seasonal 1-month SPI (five indicators)

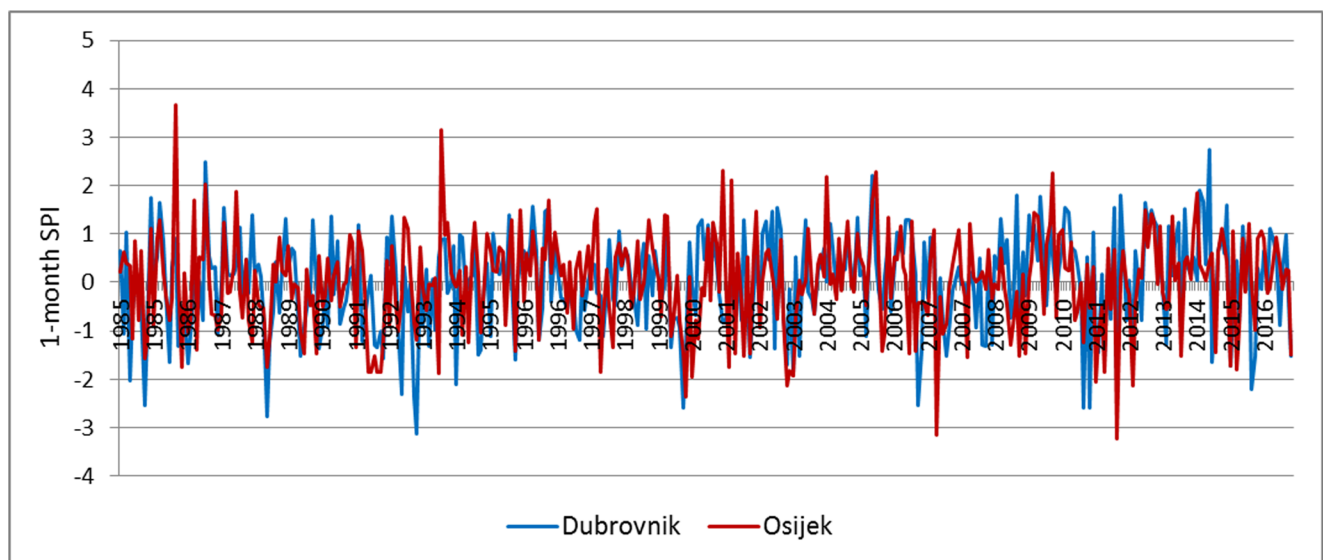


Fig. 2 Values of 1-month SPI during the period 1985–2016 for Osijek and Dubrovnik stations

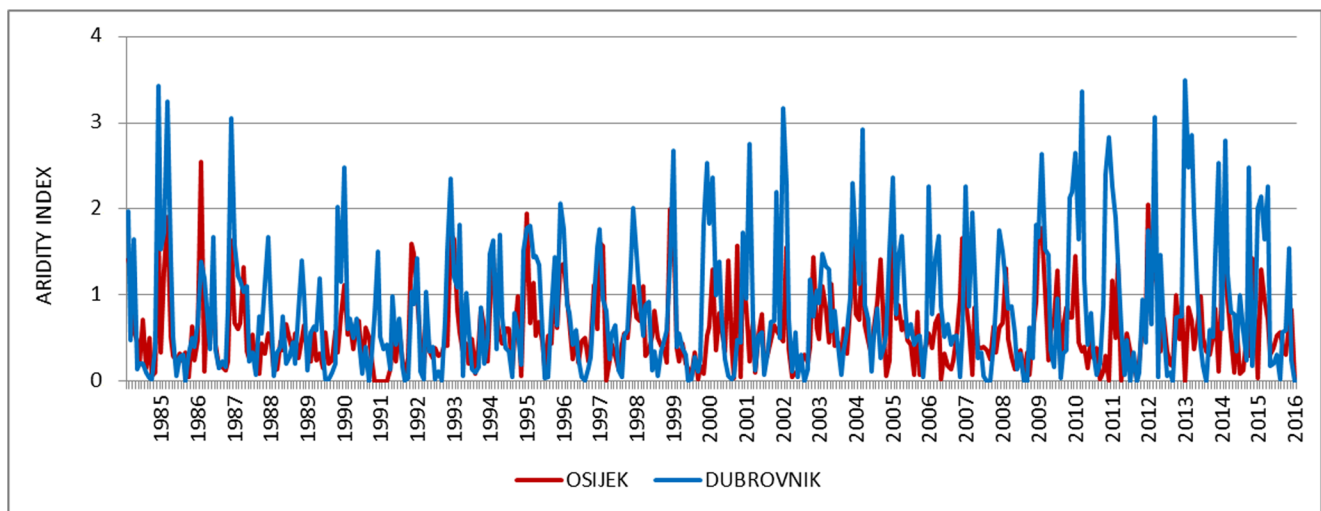


Fig. 3 Values of monthly aridity index during the period 1985–2016 for Osijek and Dubrovnik stations

Linear regression method was applied on the data series of climate change indicators on an annual and seasonal basis. Using coefficients of linear regression offers the possibility of multidimensional statistics of complex natural process (Parinet et al. 2004). The linear regression coefficients of defined variables are presented in Table 3. The most analyzed indicators have positive trends. Osijek station shows increasing trends for all indicators related to air temperature. Number of days without precipitation during autumn and winter and number of days with precipitation higher than 30 mm have negative trends, including aridity index during autumn and 1-month SPI during summer, indicating greater dryness. Dubrovnik station also shows increasing trends except for the number of days without precipitation during spring and autumn indicating more rainy days during these seasons.

PCA defines two or more components essential for description of the contribution and impact of each variable. The number of components is defined by eigenvalues > 1 . In this case, there were four key factors (F1 to F4) as shown in Fig. 6.

Key factors F1 and F2 defined for Osijek station had a contribution of approximately 69.5% and factors F3 and F4 the remainder of 30.5% (Fig. 6a).

Key factors F1 and F2 defined for Dubrovnik station had a contribution of approximately 82% (Fig. 6a). The eigenvalues of factors F3 and F4 were < 1 and thus were not further analyzed (Fig. 6b).

To find the group of variables that define the key factors, it was necessary to examine the loadings of the variables by correlations between the factors and variables. Their correlations can be positive or negative. The weight of the

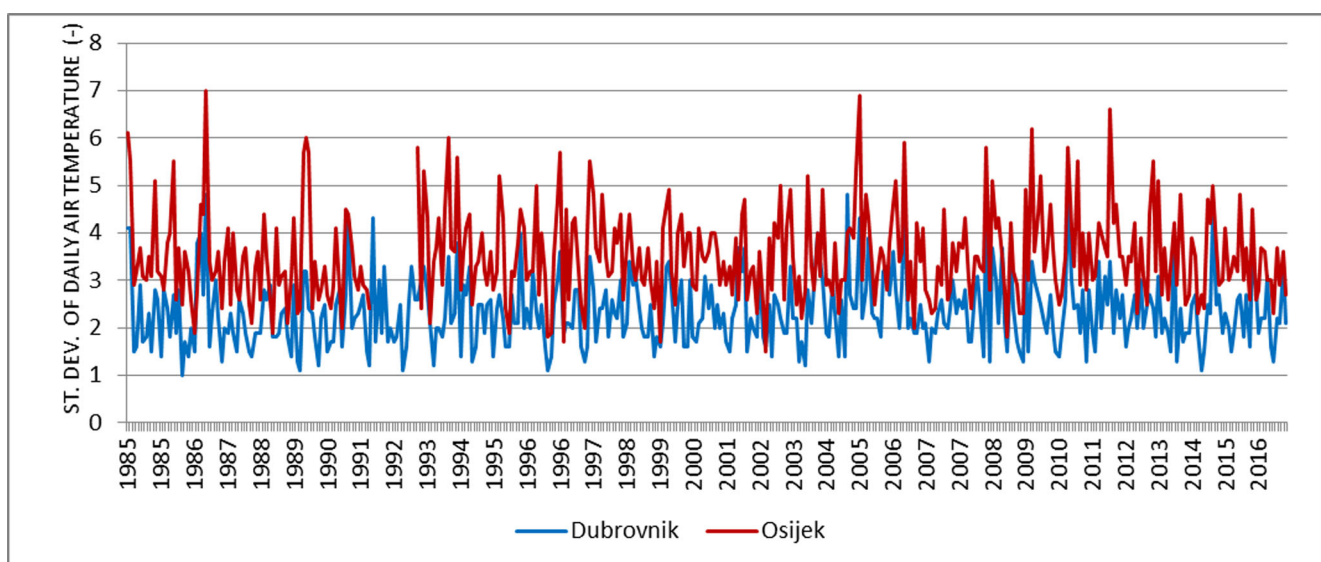


Fig. 4 Standard deviations of mean daily air temperatures during the period 1985–2016 for Osijek and Dubrovnik stations

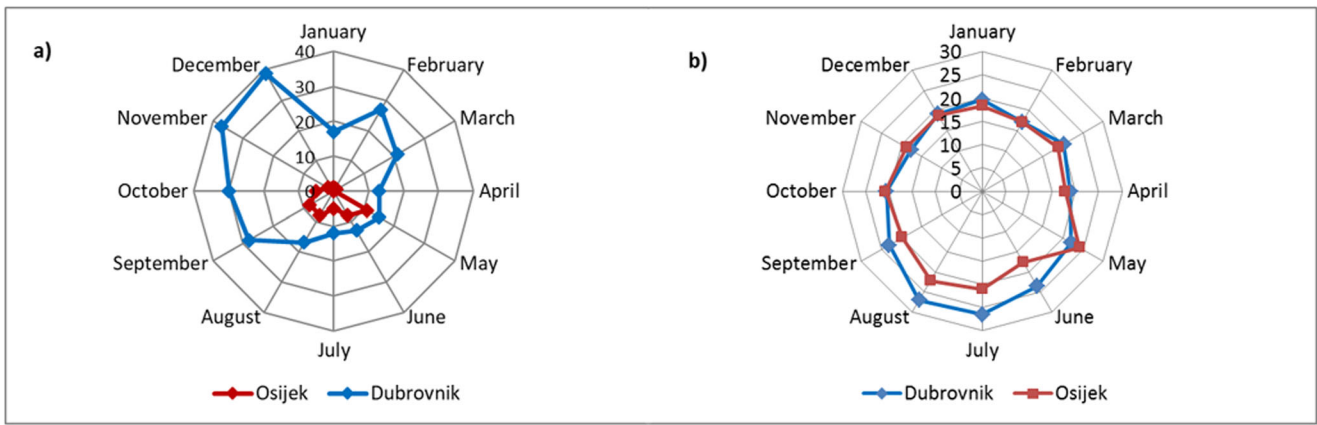


Fig. 5 Average number of days with daily precipitation > 30 mm (a) and number of days with no precipitation (b) during the period 1985–2016

relationship between 0.5 ± 0.74 was estimated as medium and greater than ± 0.75 as a strong correlation (Table 4). This can be also presented using a circle of correlation (Figs. 7a and 8a), and it is obvious that the maximum daily temperature had the least impact on climate behavior during the observed period. In other words, variables with a correlation closer to 1 have a greater impact on the process. This means that the greatest impact on climate change assessment for Osijek station was a combination of five variables: mean air temperature, number of days with precipitation > 30 mm, number of days with no precipitation, 1-month SPI, and maximum daily precipitation (total impact of F1 is 42.3%) These variables define the changes in air temperature and extremes of the meteorological parameters. Key factor F2 consists of two variables, precipitation sum and monthly air temperature sum (total impact of F2 is 27%). Key factors F3 and F4 consist of three variables as follows: maximum daily air temperature,

aridity index, and standard deviation of daily temperature (total impact of F3 and F4 is 30.7%).

This leads to the conclusion that climate change processes in the Osijek area (the continental part of the Croatia) are under a stronger influence of precipitation and air temperature changes and extremes which consequently result in higher frequencies of drought and flood, and dominant key factor consists of variables related to precipitation.

Results for Dubrovnik station as representative of a Mediterranean climate show the dominant influence of six variables: precipitation sum, mean air temperature, maximum daily air temperature, 1-month SPI, aridity index, and standard deviation of air temperature (total impact of F1 is 46%). Nearly the same influence occurs from another key factor (F2) which consists of a combination of four parameters as follows: maximum daily precipitation, monthly air temperature sum, number of days with precipitation > 30 mm, and

Table 3 Input data—linear regression coefficients

	Mean air temp.	Max daily air temp.	Monthly air temp. sum	1-month SPI	Precipitation sum	Max daily precipitation	Number of days with precipitation > 30 mm	St. dev. of daily air temp.	Aridity index	Number of days with no prec.
Osijek										
Year	0.0493	0.0444	17.352	0.0004	37.043	0.2316	0.0246	0.00224	0.00005	0.2474
Spring	0.04	0.0459	3.8664	0.00008	0.7644	0.2073	0.0148	0.0021	0.00001	0.1904
Summer	0.051	0.0704	4.8966	-0.0031	0.4711	0.2119	0.010	60.0054	0.00003	0.1697
Autumn	0.0494	0.0243	6.2129	0.003	62.129	0.2611	0.0015	0.0051	-0.000007	-0.0658
Winter	0.0566	0.048	2.376	0.0076	2.376	0.2463	-0.0024	0.00204	0.0001	-0.0469
Dubrovnik										
Year	0.0447	0.0526	0.5363	0.0012	12.657	0.8723	0.1501	0.0043	0.0007	0.1358
Spring	0.0505	0.071	0.1515	0.0015	12.638	0.4726	0.017	0.0017	0.0003	-0.0218
Summer	0.0626	0.0838	0.1878	0.0014	18.305	0.4748	0.029	0.0089	0.0003	0.0788
Autumn	0.0353	0.0316	0.1059	0.0041	2.549	0.3491	0.0376	0.0057	0.0002	-0.0049
Winter	0.0304	0.024	0.0911	0.0125	7.014	0.758	0.0665	0.001	0.0013	0.0838

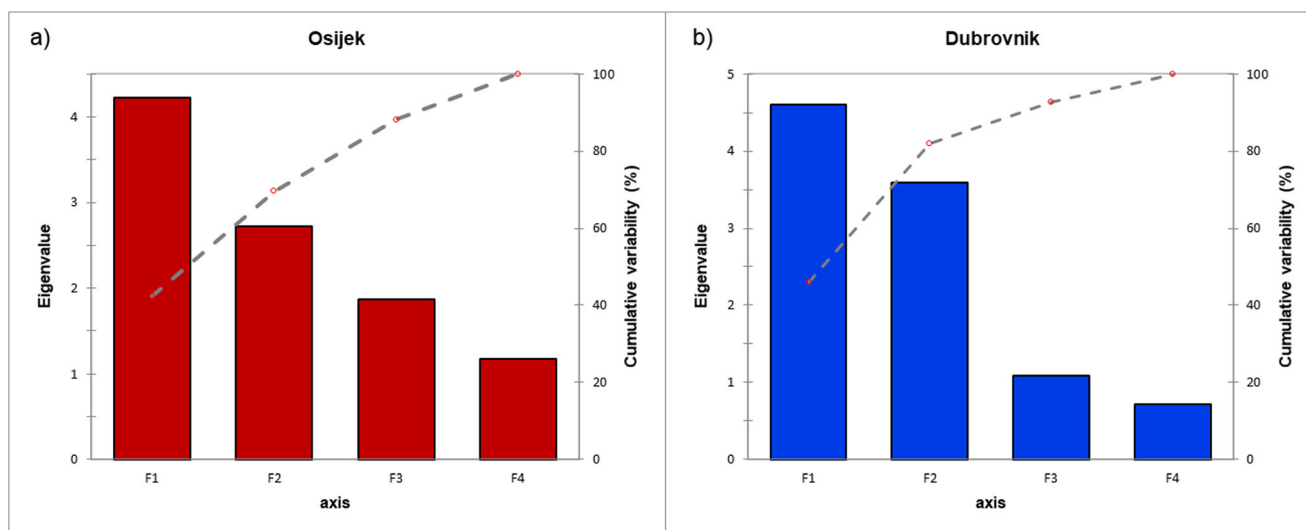


Fig. 6 Contribution of each key factor by eigenvalues: Osijek (a), Dubrovnik (b)

number of days with no precipitation (contribution of F2 is 36%) (Table 4). Comparing with the continental region of the country, the dominant key factor consists of variables related to precipitation and air temperature as well.

If we overlap previously defined key factors with the linear regression coefficients of the variables calculated for seasons (spring, summer, autumn, and winter) and the

whole year, a final conclusion can be made (Figs. 7b and 8b). In the Osijek region, changes occurring during spring, autumn, and winter are influenced by changes and extremes in precipitation and air temperature (key factor F1). Characteristics of summer changes are more under the influence of key factor F2 which is a combination of precipitation sum and monthly air temperature sum.

Table 4 Correlation between variables and factors (significant values are in italics)

	F1	F2	F3	F4
Osijek				
Precipitation sum	0.274	<i>0.936</i>	-0.150	0.161
Mean air temperature	-0.639	0.315	0.413	0.567
Monthly air temperature sum	0.527	<i>0.694</i>	-0.340	0.354
Aridity index	-0.325	0.578	<i>0.749</i>	0.006
Number of days with precipitation > 30 mm	<i>0.936</i>	0.333	-0.115	0.026
Number of days with no precipitation	<i>0.979</i>	0.131	0.158	-0.009
1-month SPI	-0.846	0.430	0.061	-0.311
St. deviation of daily air temperatures	-0.100	-0.661	-0.265	<i>0.690</i>
Max daily precipitation	-0.794	0.331	-0.452	0.235
Max daily air temperature	0.418	-0.267	<i>0.826</i>	0.266
Dubrovnik				
Precipitation sum	<i>0.634</i>	0.596	-	-
Mean air temperature	<i>0.905</i>	0.332	-	-
Monthly air temperature sum	0.008	<i>0.907</i>	-	-
Aridity index	-0.860	0.257	-	-
Number of days with precipitation > 30 mm	-0.472	<i>0.808</i>	-	-
Number of days with no precipitation	-0.312	<i>0.875</i>	-	-
1-month SPI	-0.827	-0.317	-	-
St. deviation of daily air temperatures	<i>0.686</i>	0.178	-	-
Max daily precipitation	-0.610	<i>0.796</i>	-	-
Max daily air temperature	<i>0.893</i>	0.306	-	-

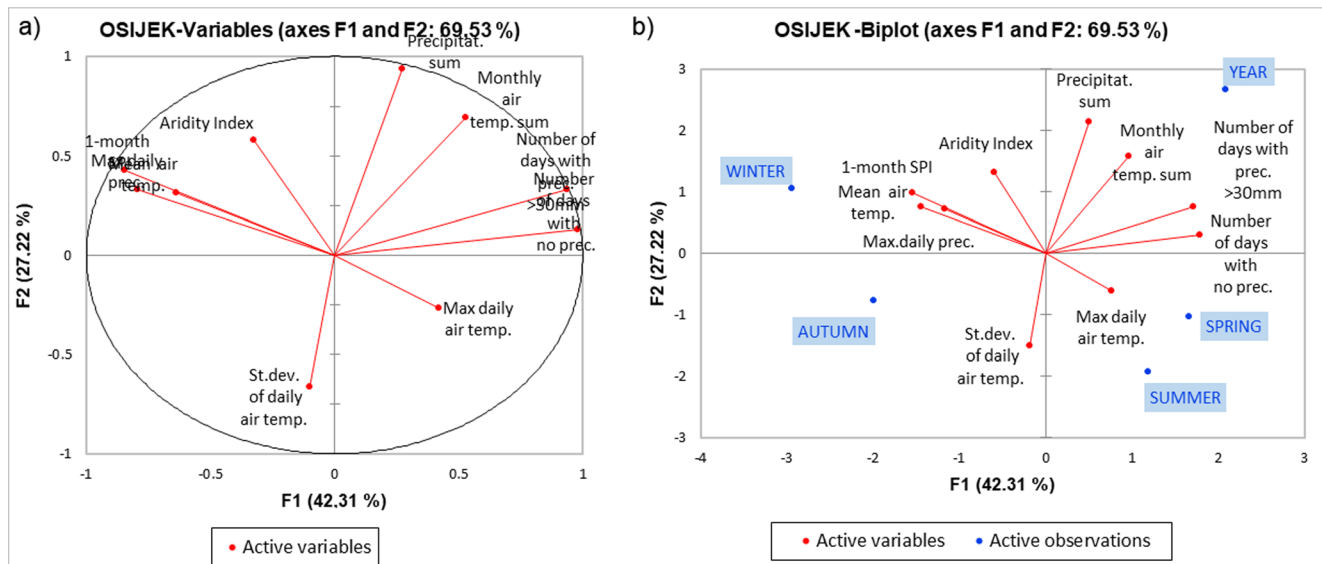


Fig. 7 Osijek—correlation circle of linear regression coefficients of defined climate change indicators (a) and biplot of key factors and observational periods (b)

Changes on an annual basis are under the influence of both key factors, F1 and F2. In addition, the least change is occurring during spring, summer, and autumn.

For Dubrovnik station, increasing air temperature and precipitation have the same importance as their variability or extreme values. There are almost no changes during spring, autumn, and winter. Summer is characterized by increasing variables related to air temperature, its variability, and maximum values including precipitation sum. Annual changes are similar to the changes in the continental climate characteristics

(Osijek station) and more related to variability in precipitation (key factor F1) (Figs. 7b and 8b).

The first step of PCA, applied to the linear regression coefficients, shows a combination of variables that influence climate change at two Croatian cities (Table 4). Despite their geographical and climatological differences, provided statistical analysis shows common characteristics for the observed period 1985–2016, particularly on an annual basis.

However, there is still the question of which of the 10 analyzed parameters have statistical significance for climate

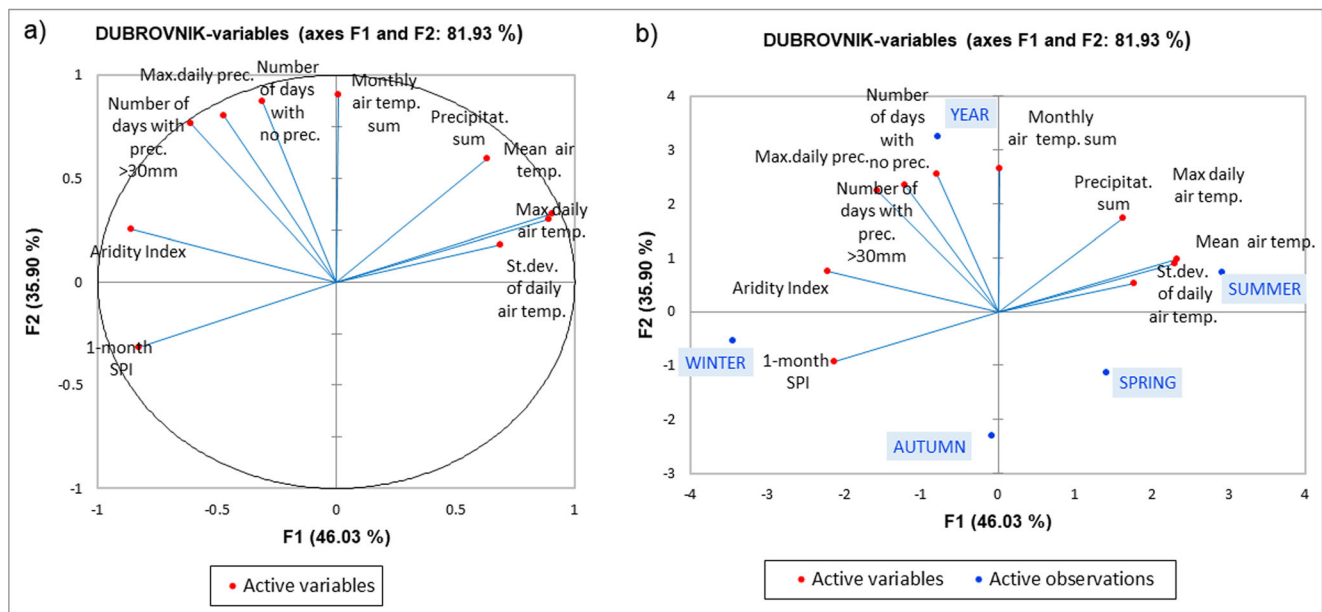


Fig. 8 Dubrovnik—correlation circle of linear regression coefficients of defined climate change indicators (a) and biplot of key factors and observational periods (b)

Table 5 Input data—Mann–Kendall test Z_{MK} coefficients (significant coefficients are in italics)

	Mean air temp.	Max daily air temp.	Monthly air temp. sum	1-month SPI	Precipitation sum	Max daily precipitation	Number of days with precipitation > 30 mm	Aridity index
Osijek								
Year	<i>3.75***</i>	<i>3.10**</i>	<i>2.45*</i>	0.83	–	–	–	
Spring	<i>1.87⁺</i>	<i>1.98*</i>	1.64	0.23	–	–	–	
Summer	<i>3.12**</i>	<i>3.08**</i>	<i>3.05**</i>	–0.86	–	–	–	
Autumn	<i>2.56*</i>	1.28	<i>2.19*</i>	0.91	–	–	–	
Winter	<i>1.95⁺</i>	<i>2.04*</i>	0.99	<i>1.67⁺</i>	–	–	–	
Dubrovnik								
Year	<i>4.02***</i>	<i>4.09***</i>	<i>4.07***</i>	<i>1.96⁺</i>	<i>2.16*</i>	1.35	<i>2.75**</i>	<i>1.90⁺</i>
Spring	<i>2.55*</i>	<i>3.00**</i>	<i>2.55*</i>	0.66	0.83	0.55	0.73	0.54
Summer	<i>3.44***</i>	<i>3.91***</i>	<i>3.47***</i>	0.29	0.66	1.05	1.11	0.66
Autumn	<i>2.03*</i>	1.31	<i>1.99⁺</i>	1.05	0.92	0.21	1.29	0.08
Winter	<i>1.66⁺</i>	1.04	1.51	<i>2.92**</i>	<i>2.61**</i>	<i>1.99*</i>	<i>1.81⁺</i>	<i>2.25*</i>

***Trend at $\alpha = 0.001$ level of significance; **trend at $\alpha = 0.01$ level of significance; *trend at $\alpha = 0.05$ level of significance; ⁺ trend at $\alpha = 0.1$ level of significance

change in Dubrovnik and Osijek. To determine the existence of significant temporal tendencies in the indicator values, the well-known Mann–Kendall non-parametric test was applied (Mann 1945; Kendall 1962; Gilbert 1987; Asfaw et al. 2018). During the second step, PCA was applied on the computed Mann–Kendall test statistic, Z_{MK} .

The test statistics Z_{MK} is described as:

$$ZMK = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (1)$$

where positive and negative values depict an upward and downward trend for a certain period.

Input data are presented in Table 5. In comparison with that shown in Table 3, the number of variables has been reduced. Only variables assessed as significant for at least one analyzed period (year, spring, summer, autumn, and winter), according to the Mann–Kendall trend test, were involved in the second PCA analysis. For the four tested significance levels, the following symbols are used: *** if trend at $\alpha = 0.001$ level of significance; ** if trend at $\alpha = 0.01$ level of significance; * if trend at $\alpha = 0.05$ level of significance; ⁺ if trend at $\alpha = 0.1$ level of significance (Table 5) (Salmi et al. 2002).

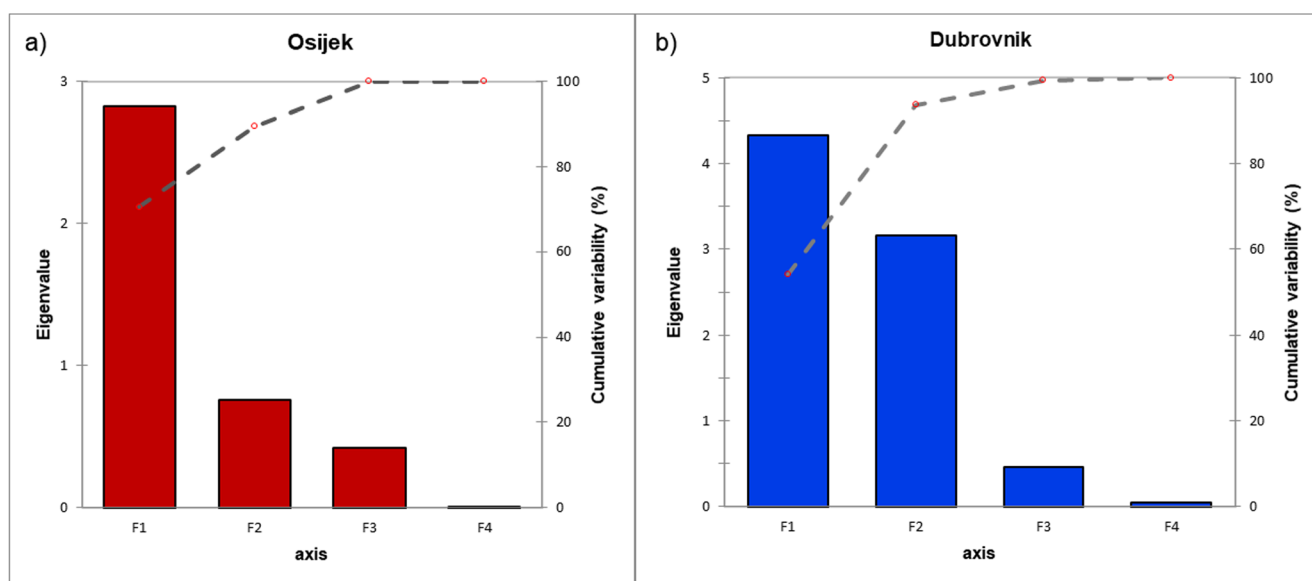


Fig. 9 Contribution of each key factor by eigenvalue: Osijek (a), Dubrovnik (b)

Table 6 Correlation between variables and factors (significant values are in italics)

	F1	F2
Osijek		
Mean air temperature	<i>0.845</i>	–
Monthly air temperature sum	<i>0.934</i>	–
1-month SPI	– <i>0.757</i>	–
Max daily air temperature	<i>0.814</i>	–
Dubrovnik		
Precipitation sum	<i>0.990</i>	0.082
Mean air temperature	–0.200	<i>0.979</i>
Monthly air temperature sum	–0.231	<i>0.972</i>
Number of days with precipitation > 30 mm	<i>0.709</i>	0.557
1-month SPI	<i>0.981</i>	–0.125
Max daily precipitation	<i>0.873</i>	0.213
Max daily air temperature	–0.337	<i>0.916</i>
Aridity index	<i>0.957</i>	0.199

According to this criterion, for Osijek station, there were four variables—mean air temperature, maximum daily air temperature, monthly air temperature sum, and 1-month SPI. The other variables related to climate variability were not significant and not further analyzed. Significant variables related to air temperature all showed a positive (increasing) trend.

There were eight variables distinguished as significant for Dubrovnik station. Compared with the linear regression coefficients shown in Table 3, only the standard deviations of daily air temperature and the number of days with no precipitation in

a month were eliminated as non-significant variables. Significant variables all have a positive (increasing) trend, and the most intensive changes occur during winter, which finally have impacts on an annual basis. Again, as in Osijek, positive trends of the variables related to air temperature have strong impacts on the climate of the seasons and the whole year as well.

Figure 9a shows key factor F1 as only relevant for Osijek station with a total loading of 70.5%. It is a combination of all significant variables, mean air temperature, monthly air temperature sum, maximum daily temperature, and 1-month SPI which show a negative correlation value of – 0.757 indicating intensification of drought (Table 6).

Figure 9b shows the contribution of two key factors (F1 and F2) with a total loading of 93.6% (Dubrovnik station). The first principle component (F1) consists of a combination of precipitation sum, 1-month SPI, and maximum daily precipitation, aridity index, and number of days with precipitation > 30 mm (54.1%), and the second (F2) is a combination of mean air temperature, monthly air temperature sum, and maximum daily air temperature (Table 6).

According to the trend significance of variables defined for Osijek station, the most important are variables related to air temperature and 1-month SPI which indicates increasing winter wetness. There are no significant changes during spring and autumn, and summer and the whole year are strongly under a warming influence. Variables related to precipitation are not significant, and the PCA results of the observed period (1985–2016) do not confirm any significant change in the precipitation regime (Fig. 10).

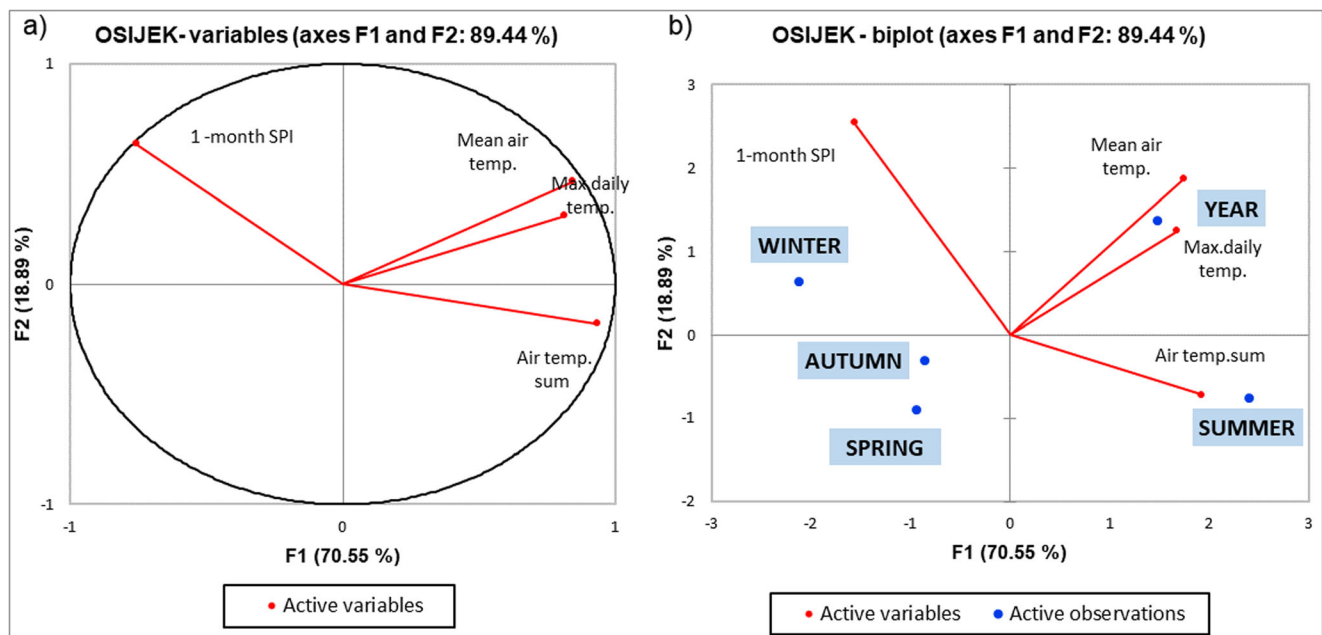


Fig. 10 Osijek—correlation circle of Mann–Kendall Z coefficients of defined climate change indicators (a) and biplot of key factors and observational periods (b)

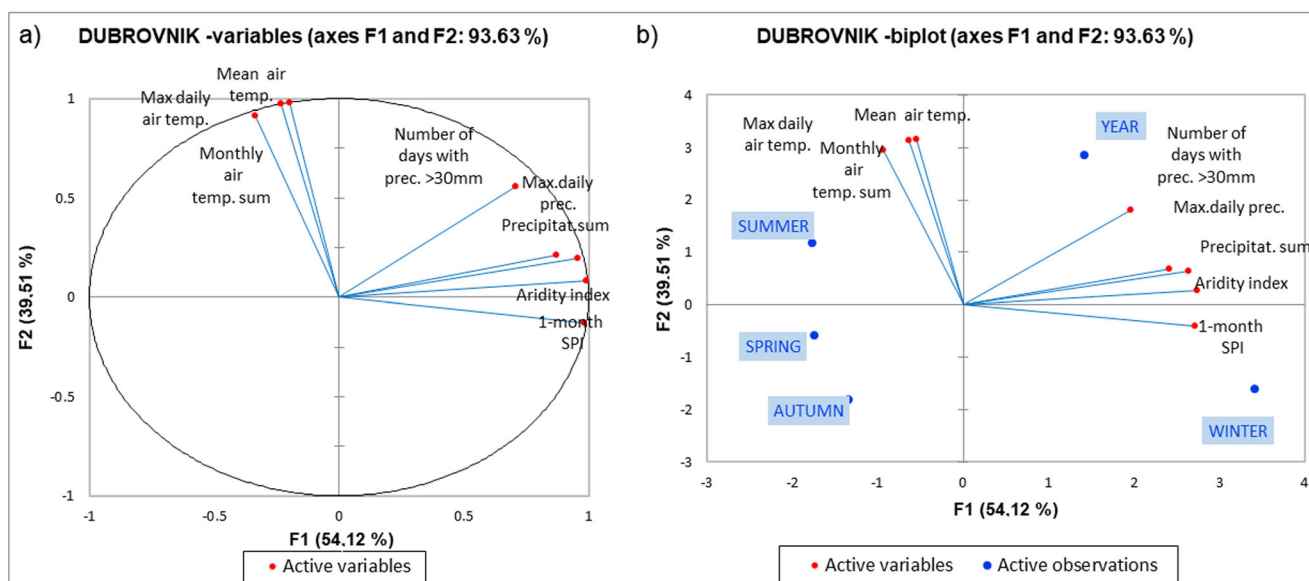


Fig. 11 Dubrovnik—correlation circle of Mann–Kendall Z coefficients of defined climate change indicators (a) and biplot of key factors and observational periods (b)

The meteorological characteristics of Dubrovnik station are more complex (Fig. 11). Spring and autumn show no changes during the period 1985–2016. Characteristics of winter are under the influence of F1 key factor (x -axis) which consists of variables related to precipitation changes. Summers are under the strong influence of variables related to air temperature, max daily temperature, mean annual and seasonal temperature, and monthly air temperature sum (F2 key factor). All eight defined climate change indicators have an impact on an annual basis. However, the annual characteristics are closer to the F1 key factor (x -axis) which consists of variables related to precipitation changes.

4 Conclusion

The provided research shows a need for more comprehensive analysis of climate change including a larger set of relevant parameters and their joint impacts. It also proves PCA is a very useful tool for implementing this approach, particularly in the Mediterranean region which shows high sensitivity to many variables important for climate characterization. Climate change assessment is usually based upon air temperature and precipitation changes on an annual and seasonal basis, but there are more levels to their significance as presented by parameters derived from these two basic parameters. However, for more comprehensive study of climate change analysis, time series should be much longer than 30 years and number of meteorological stations involved in analysis should be larger, but this research emphasizes application of PC analysis as a tool in climate change assessment of any region.

Data series of air temperature and precipitation, together with climate change indicators derived from these two basic parameters, were analyzed on a monthly, seasonal, and annual basis during the period 1985–2016 for two meteorological stations—Osijek in the continental (northern) region of Croatia and Dubrovnik in the Mediterranean (southern) region. There are 10 defined indicators presenting climate variability, frequencies of extremes, and the general increasing or decreasing of parameters related to precipitation and air temperature. Despite geographical and climatological differences, application of PCA on linear regression coefficients showed many similarities. Results of PCA applied on Mann–Kendall statistic Z_{MK} also confirmed many similarities. In the continental region (Osijek station), changes are obvious on an annual and seasonal basis even though they are statistically significant only on an annual basis and summer. In the continental region of the country, there are no significant changes during spring and autumn. Summer and the whole year are strongly under a warming influence, and more precipitation occurs during winter (increasing the 1-month SPI). Results related to warming are consistent with climate change investigations in neighboring Hungary and Serbia but less consistent with projections of precipitation increasing in the near future.

The meteorological characteristics of Dubrovnik station show that most of the changes influence the whole year and summer and there are no significant changes during spring, autumn, and winter. The climate change scheme of the Dubrovnik region is more complex including joint impacts of warming and more precipitation which is not typical for the Mediterranean region and to some extent opposite to climate projections for the near future in which precipitation is

expected to decrease in southern Croatia during spring. This analysis supports conclusions regarding increasing extreme precipitation typical for the Mediterranean region. In this case, projections concerning precipitation, which is much more locally variable, seem to be less accurate.

In addition, this study shows the complexity of climate change processes and the importance of the observation scale. Conclusions and scenarios defined at a regional scale are often less applicable to those at a local level.

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