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ORIGINAL PAPER

Recent changes in Serbian climate extreme indices from 1961 to 2010

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Abstract The evolution of daily extreme temperature and precipitation from 1961 to 2010 in Serbia was investigated. Trends of five temperature indices, three precipitation indices, and four combined indices were calculated at ten temperature and ten precipitation stations located within the study area, and their corresponding significances were tested using the Student's *t* test. Obtained results suggest that the time periods of extremely hot weather last longer, while the periods of extremely cold weather are shortened. Trends of duration of extreme temperature conditions were most pronounced in summer season. Periods of mild weather conditions are extended. Amount and intensity of precipitation had statistically significant increase only during autumn and were most pronounced in the northern and western parts of the country. On an average, there was no significant decrease in the maximum number of consecutive dry days or increase in the wet days (except in autumn). The investigation of four combined temperature-precipitation regimes showed the domination of "dry" regimes over "wet," increasing trend of "warm" regimes and decreasing trend of "cold" regimes. The correlation between the examined extreme indices and the large-scale circulation patterns showed that EA and NAO had significant influence on duration of winter warm periods, while their influence on duration of cold periods cannot be confirmed with certainty.

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1 Introduction

Climate change is one of the most significant challenges facing international community, due to potential severe consequences on natural and anthropogenic ecosystems, health, and economy. Modifications in climate are visible in different climate variables, including air temperature and precipitation. Analyses of observed temperature in many regions of the world have revealed that the mean temperature has increased over the last century. It is assumed that the human impact induced an increase of the global mean air temperature between 0.4 and 0.8 °C in the last 100 years. Between 1956 and 2005, the temperature increase of 0.13 °C decade^{-1} was nearly double compared to the previous 100 years from 1906 to 2005 (IPCC 2007). Besides increasing average temperatures, more extreme temperature and precipitation events are also the consequences of the climate change.

Temperature and precipitation extremes have been studied at global (Easterling et al. 1997; Frich et al. 2002; Alexander et al. 2006), regional (Peterson et al. 2002; Klein Tank and Konnen 2003; Vincent et al. 2005; Aguilar et al. 2005; Choi et al. 2009; Peterson et al. 2008), and national levels (Hundecha and Bardossy 2005; Costa and Soares 2009; Kioutsioukis et al. 2010; El Kenawy et al. 2011; Buric et al. 2014, etc.). There is significant consistency among the results obtained from these studies in terms of temperature extremes, while spatial coherence of precipitation extremes is less. Most studies agree that the greatest increases have been with extreme minimum temperatures (Easterling et al. 1997; Frich et al. 2002), while increases of extreme maximum temperatures are also perceptible, but not with the same significance as increases of extreme minimums. In contrast to the findings presented for a global scale, the results obtained for different European regions, such as the Carpathian Basin in central/eastern Europe (Bartholy and Pongracz 2007), extra-

Carpathian regions of Romania (Croitoru and Piticar 2013), western Germany (Hundecha and Bardossy 2005), or north-eastern Spain (El Kenawy et al. 2011), showed that the daily maximum temperature is becoming more extreme, whereas the minimum is less extreme. Beside temperature extremes, surface precipitation has correspondingly increased in the mid to high latitudes over the same period. However, several studies show the decreasing precipitation trend in the Balkan Peninsula, indicating tendencies toward a drying climate over time, which is contrary to the increasing trend in mid to high latitudes (Sharov et al. 2000; Alexandrov et al. 2004; Kostopoulou and Jones 2005). Existing studies report a global tendency of increasing frequency of the very heavy precipitation and the decreases of light and moderate precipitation in the last few decades (Karl and Knight 1998; Manton et al. 2001; Klein Tank and Konnen 2003). The analysis of joint temperature-precipitation climate indices revealed a systematic change at nine European cities during the twentieth century with sharp rise in the frequency of occurrence of the "warm" regimes and significant decline of the "cold" regimes (Beniston 2009).

Along with the rest of the world, Serbia has experienced temperature changes during recent decades. A review of the climate change in Serbia so far, as well as the climate projections for the twenty-first century, has been given in the Serbia's First National Communication (MESP 2010). The annual mean surface air temperature has increased significantly in almost all parts of Serbia, except southeast part of the country. The rises in temperatures were higher in the northern than in the southern parts of Serbia, and the increase was the highest in spring. The precipitation amount observed in the period 1946–2006 has had an increasing trend in most parts of the territory of Serbia. The highest increasing trend in annual precipitation was in the west of the country whilst the highest decreasing trend was in the southeast. Northern Serbia had a higher increase in precipitation in summers and autumns, as well as annually than southern Serbia. According to Unkasevic and Tosic (2013), the largest warming tendencies in a number of warm days and nights were found in summer, while cooling tendency of cold and frost days was only during autumn.

The objective of this study is to quantify changes in temperature and precipitation extremes during 1961–2010 throughout Serbia. The previous studies over Serbia primarily focused on the trends of percentile-based and threshold-based temperature extremes (Unkasevic and Tosic 2013; Malinovic-Milicevic et al. 2013) and analysis of the daily maximum and monthly precipitation (Unkasevic and Tosic 2007). From the duration-based indices, just heat waves were analyzed, in only four places in Serbia (Unkasevic and Tosic 2009; Drljaca et al. 2009; Malinovic-Milicevic 2013). In order to provide a comprehensive analysis of the recent climate modifications, this paper primarily concentrates on temperature and precipitation duration-based indices which define periods of excessive warmth, cold, wetness, or dryness (or in the case of growing season length, periods of mildness), as well as short-term precipitation intensity. In addition, to describe the common effect of precipitation and temperature, quantile-based combined indices are also analyzed.

2 Data and methods

2.1 Study area

The study area is the territory of the Republic of Serbia without the Province of Kosovo and Metohija. The Republic of Serbia is continental country, mainly located in south–eastern Europe, in the central part of the Balkan Peninsula (Fig. 1). The smaller, northern part of the country belongs to Central Europe. Northern Serbia is mainly flat, while the central parts are highlands. Going to the south, the hills gradually turn into mountains. Due to its geographical position and meridional orientation, climate in Serbia varies from moderate continental in northern to continental in central parts of the country. Southern and southwestern parts of the country are subjected to the Mediterranean influences, while a typical mountain climate can be found on high mountains (Lalic et al. 2013). Mean annual air temperatures are between 3 °C at altitudes above 1500 m and 12 °C in the lowlands (period 1961–1990). The coldest month is January, and the warmest is July. The sum of the annual precipitation increases with altitude. The lowest precipitation, under 600 mm, is characteristic for northern Serbia. The amounts of precipitation in the Sava valley region and in the Great Morava and South Morava valley regions range between 600 and 700 mm, in the mountainous areas between 800 and 1000 mm a year, and above 1000 mm a year on some mountain peaks in Southwest Serbia.

2.2 Data sources

Climatological data used in this study are a set of daily precipitation and temperature data during the period 1961–2010, provided by Serbian meteorological service. Ten stations were selected for the analysis of temperature and precipitation extremes (Fig. 1 and Table 1). During the observation period, locations of stations did not change. Measurements were performed every day using the same type of instruments. The spring (Mar–May), summer (Jun–Aug), and autumn (Sep–Nov) seasons correspond to the calendar year but the winter season (Dec–Feb) corresponds to January–February of the calendar year and to December of the previous year. Quality control and homogeneity test procedure were performed using

Fig. 1 Location of Serbia in Europe and meteorological stations in Serbia used in this study

Climdex version 1.3 software developed by Byron Gleason from NDC/NOAA, USA (http://etccdi.pacificclimate.org/homogenization.shtml).

2.3 Extreme indices

We used five temperature indices, three precipitation indices and four combined indices in this study (Table 2), many of which are defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI).

The GSL variable is especially meaningful in the mid-latitude regions, and, aside from agricultural use, it can be considered an indicator of the duration of mild/favorable weather (Insaf et al. 2013). Overall count of days in long periods of extreme warm and cold weather was defined by WSDI and CSDI, respectively. The length of the greatest warm and cold spells is shown by MCWD and MCCN.

The length of the greatest dry and wet spells is shown by CDD and CWD. Regarding the CDD and CWD indices, a wet day is defined as a day with at least 1 mm of precipitation (R≥1 mm); thus, a dry day has less than 1 mm of precipitation (R<1 mm). Ceballos et al. (2004) claim that precipitation amounts below 1 mm are not absorbed by soils and are evaporated off directly. The RX5day provides a measure of short-term precipitation intensity and can be considered a flood indicator (Costa and Soares 2009).

Table 1 List of stations with their abbreviations, latitudes, longitudes, altitudes, and used meteorological data

Abbreviation	Station	Latitude	Longitude	Altitude (m)	Temperature/precipitation
SU	Subotica	46° 06′	19° 46′	102	+/+
NS	Novi Sad	45° 20′	19° 51′	86	+/+
BG	Beograd	44° 48′	20° 28′	132	+/+
VG	Veliko Gradiste	44° 45′	21° 31′	80	+/+
LO	Loznica	44° 33′	19° 14′	121	+/+
KG	Kragujevac	44° 02′	20° 56′	185	+/+
ZL	Zlatibor	43° 44′	19° 43′	1028	+/+
NI	Nis	43° 20′	21° 54′	204	+/+
VR	Vranje	42° 33′	21° 55′	432	+/+
NG	Negotin	44° 14′	22° 33′	42	−/+
VB	Vrnjacka Banja	43° 37′	20° 54′	235	+/−

Table 2 Definitions of the indices used in this study

Index	Descriptive name	Definition	Units
Indices of temperature extremes			
GSL[a]	Growing season length	Annual count of days between first span of at least 6 days where daily mean temperature (Ta) >5 °C and first span in second half of the year of at least 6 days where Ta <5 °C.	days
WSDI[a]	Warm spell duration index	Count of days in a span of at least 6 days where daily maximum temperature (Tx) >90th percentile	days
CSDI[a]	Cold spell duration index	Count of days in a span of at least 6 days where daily minimum temperature (Tn) <10th percentile	days
MCWD	Maximum consecutive warm days	Maximum number of consecutive days where Tx >90th percentile	days
MCCN	Maximum consecutive cold nights	Maximum number of consecutive nights where Tn <10th percentile	days
Indices of precipitation extremes			
RX5day[a]	Maximum 5-day precipitation	Highest consecutive 5-day period precipitation amount	mm
CDD[a]	Consecutive dry days	Maximum number of consecutive days where daily precipitation amount (R) <1 mm	days
CWD[a]	Consecutive wet days	Maximum number of consecutive days where R≥1 mm	days
Indices of combined extremes			
WD	Warm/dry days	Number of days with Ta >75th percentile and R<25th percentile	days
WW	Warm/wet days	Number of days with Ta >75th percentile and R>75th percentile	days
CD	Cold/dry days	Number of days with Ta <25th percentile and R<25th percentile	days
CW	Cold/wet days	Number of days with Ta <25th percentile and R >75th percentile	days

Indices in italics represent those available seasonally

[a] Recommended by the ETCCDI

In order to define particular modes of heat and moisture, we used the combined temperature and precipitation indices (WD, WW, CD, and CW). They refer to the excess of the joint quantiles of temperature and precipitation using the 25 and 75 % quantile levels as an intermediary threshold between using just the median as a separation of modes and more

Table 3 Linear decadal trends in annual maximum and minimum temperatures and extreme temperature indices in Serbia, 1961–2010

	T_x	T_n	GSL	WSDI	CSDI	MCWD	MCCN
SU	0.313[a]	0.357[a]	3.515	3.689[a]	−0.329	0.910[a]	−0.326
NS	0.248[a]	0.293[a]	5.499[b]	2.184[a]	−0.932	0.885[a]	−0.291
BG	0.316[a]	0.367[a]	6.422[b]	3.194[a]	−1.021[c]	0.993[a]	−0.309
VG	0.327[a]	0.105[b]	3.617	4.830[a]	−0.177	1.323[a]	0.020
LO	0.310[a]	0.340[a]	3.502	2.971[a]	−0.506	0.819[a]	−0.281
KG	0.358[a]	0.316[a]	5.342[c]	3.429[a]	−0.691	0.931[a]	−0.313
ZL	0.513[a]	0.226[a]	5.994[b]	5.978[a]	−0.236	1.455[a]	−0.032
NI	0.377[a]	0.236[a]	5.014[c]	3.707[a]	0.030	0.961[a]	−0.085
VR	0.387[a]	0.000	1.185	4.758[a]	0.571	0.878[a]	0.236
VB	0.436[a]	0.191[a]	4.461	5.969[a]	−1.000	1.487[a]	−0.099
Year	0.351[a]	0.240[a]	4.468[b]	3.994[a]	−0.387	1.029[a]	−0.140
Spring	0.430[a]	0.214[b]	–	–	–	0.395[c]	−0.020
Summer	0.567[a]	0.387[a]	–	–	–	1.060[a]	−0.331[a]
Autumn	0.064	0.112	–	–	–	0.566	0.087
Winter	0.499[a]	0.328[b]	–	–	–	0.829[a]	−0.197

[a] Statistical significance at the 99 % level ($p \leq 0.01$)

[b] Statistical significance at the 95 % level ($0.01 < p \leq 0.05$)

[c] Statistical significance at the 90 % level ($0.05 < p \leq 0.10$)

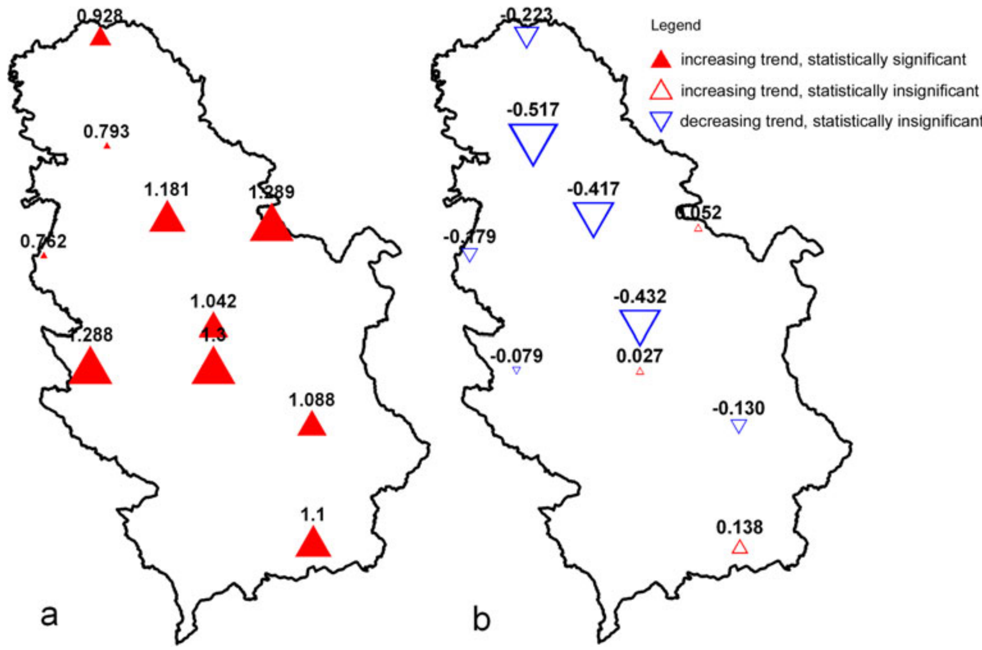

Fig. 2 Trends for the **a** maximum consecutive warm days (MCWD) for the summer months (Jun−Aug) and **b** maximum consecutive cold nights (MCCN) for the winter months (Dec−Feb) in Serbia for the period 1961–2010

constraining or "extreme" quantiles. The use of joint quantiles includes a larger number of events and allows an exploration of climate statistics that in many instances would be overlooked by simply analyzing single quantile thresholds of temperature or precipitation (Beniston 2009). Quantile thresholds are calculated using the daily mean temperature and 24-h precipitation totals for each season of the 30-year baseline period 1961–1990.

2.4 Statistical parameters

The slopes of the trends in the indices were calculated by least squares linear fitting. To obtain the change per decade, the slope was multiplied by ten. The significance of the trend was assessed using the Student's *t* test at the 90 % ($0.05<p$ value≤ 0.10), 95 % ($0.01<p$ value≤ 0.05), and 99 % (p value≤ 0.01) significance level. This test evaluates significance of the trend via trend magnitude, i.e., the *t* test statistic is the ratio of the estimate of the magnitude of trend or its slope to its standard deviation (Yue and Pilon 2004). To assess the correlation between the examined extreme indices and the large-scale circulation patterns, we used the Pearson correlation coefficients at the 90, 95, and 99 % significance level.

2.5 Large-scale atmospheric circulation patterns

In order to describe the relationship between the extreme indices and the large-scale atmospheric circulations, we investigate the NAO, EA, and EAWR patterns.

The North Atlantic Oscillation (NAO) pattern is especially important in winter, when it has a large impact on the climate of the Northern Hemisphere (Hurrell 1995). In the positive NAO phase, there is stronger zonal flow over the North Atlantic which brings warmer moister air to Europe. According to Castro-Dıez et al. (2002), the relationship between the NAO variability and the temperatures in southern

Table 4 Linear decadal trends in precipitation sums and extreme precipitation indices in Serbia, 1961–2010

	R	RX5day	CDD	CWD
SU	20.850[c]	5.241[a]	−0.591	−0.070
NS	31.329[b]	3.702[c]	−2.433[b]	0.220[c]
BG	13.276	−0.614	−0.585	0.033
VG	0.645	−0.220	−1.153	−0.032
LO	28.540[b]	6.714[b]	0.189	−0.153
KG	5.082	0.248	−0.105	0.006
ZL	37.115[a]	3.154	0.300	0.358[b]
NI	6.080	−1.004	−0.847	0.248
VR	−9.041	0.432	−1.007	0.085
NG	−4.935	1.772	0.998	0.090
Year	13.408[c]	2.065[b]	−0.584	0.061
Spring	−1.568	−0.105	0.045	−0.079
Summer	2.106	1.444	0.343	0.104[c]
Autumn	10.141[b]	3.124[b]	−1.626[c]	0.174[a]
Winter	−0.856	0.683	0.087	−0.063

[a] Statistical significance at the 99 % level ($p<0.01$)
[b] Statistical significance at the 95 % level ($0.01\leq p<0.05$)
[c] Statistical significance at the 90 % level ($0.05\leq p<0.10$)

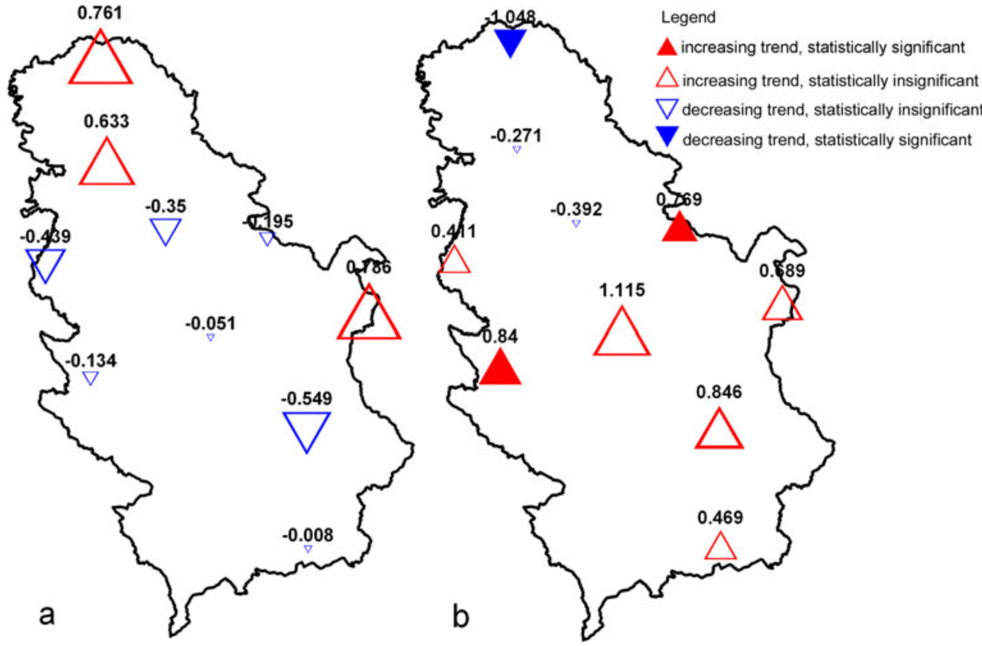

Fig. 3 Trends for the consecutive dry days (CDD) for **a** the spring months (Mar–May) and **b** the summer months (Jun–Aug) in Serbia for the period 1961–2010

Europe substantially differs with respect to central and northern Europe, where no such sensitivity regarding the location of the NAO action centers is found. The negative phases of the NAO tend to be associated to increased storm activity and precipitation in southern Europe, while strong positive phases of the NAO lead to below-average precipitation over southern and central Europe.

The East Atlantic (EA) pattern is different from the NAO because it contains more subtropical influences (Unkasevic and Tosic 2013). The positive phase of the EA is associated with above-average surface temperatures in Europe in all months and below-average precipitation across southern Europe.

The East Atlantic/West Russia (EAWR) pattern is active during winters. According to Krichak and Alpert (2005) the EAWR/precipitation correlations are statistically significant over the eastern Atlantic and southeastern Mediterranean regions. During the negative (positive) EAWR phases, wetter (drier) than normal weather conditions are observed over a large part of the Mediterranean region (Barston and Livezey 1987).

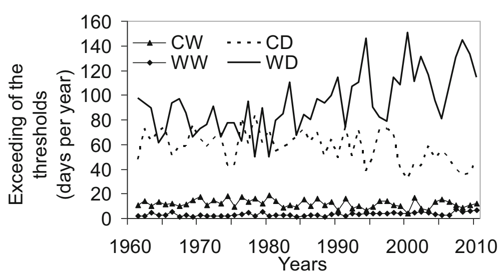

Fig. 4 Exceeding of the joint quantile thresholds for the four joint temperature and precipitation regimes (CD, CW, WD, WW) for Serbia

3 Results and discussion

3.1 Annual and seasonal changes in temperature means and extreme temperature duration indices

This section gives an overview of trend results for temperature means and each of the investigated temperature

Table 5 Linear decadal trends in combined temperature and precipitation indices in Serbia, 1961–2010

	WD	WW	CD	CW
SU	11.613[a]	0.896[a]	−5.933[a]	−0.045
NS	8.599[a]	0.475[a]	−3.727[a]	0.234
BG	10.960[a]	0.527[a]	−4.464[a]	−0.608
VG	8.067[a]	0.618[a]	−2.087	−1.147[a]
LO	11.643[a]	0.933[a]	−4.887[a]	−0.518[c]
KG	11.915 [a]	0.496[a]	−4.690[a]	−1.118[a]
ZL	8.613[a]	0.664[a]	−3.673[a]	−0.368[c]
NI	11.211[a]	0.442[b]	−4.833[a]	−0.525
VR	7.237[a]	0.181	−2.673[c]	−0.976[a]
Year	9.983[a]	0.572[a]	−4.133[a]	−0.551[c]
Spring	2.006[b]	0.108[b]	−1.172[b]	−0.318[b]
Summer	4.723[a]	0.088[b]	−2.385[a]	−0.050
Autumn	0.961	0.082[c]	0.245	0.213[c]
Winter	2.387[a]	0.196[b]	−1.094	−0.274[b]

[a] Statistical significance at the 99 % level ($p<0.01$)

[b] Statistical significance at the 95 % level ($0.01\leq p<0.05$)

[c] Statistical significance at the 90 % level ($0.05\leq p<0.10$)

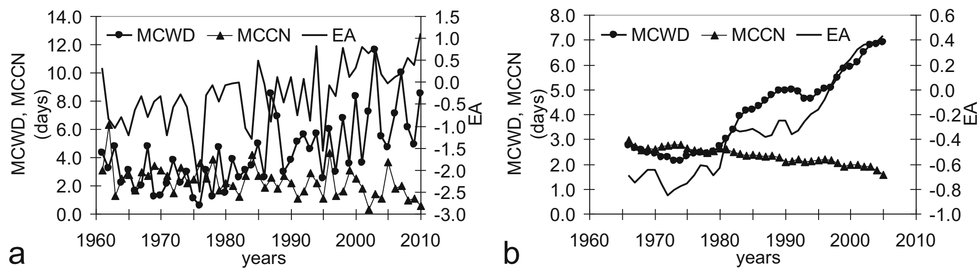

Fig. 5 Maximum consecutive warm days (MCWD) and maximum consecutive cold nights (MCCN) against the EA index during the summer season: **a** original values and **b** decadal moving average values

indicators. The results obtained after the application of the Student's t test to all series of indices are summarized in the Table 3.

The annual average daily maximum and minimum air temperatures have increased at rates of 0.35 and 0.24 °C decade^{-1} from 1961 to 2010, respectively. Increasing trends of maximum and minimum temperature in almost all measuring stations are statistically significant. The increasing rates of minimum temperature for the stations at the north are greater than those of annual maximum temperature. The significant changes in annual maximum and minimum temperature means are associated with noticeable changes in the frequency of extreme temperature events. Most extreme temperature duration-based indices showed trends consistent with warming during the period of analysis. Linear trend analyses of extreme duration-based temperature indices showed that the frequency of WSDI and MCWD has increased across Serbia by 3.994 and 1.029 days decade^{-1}, respectively, whereas MCWD and MCCN have decreased by 0.387 and 0.140 days decade^{-1}, respectively, over the 1961–2010 period. However, increasing trend of warm duration indices was statistically significant, while decreasing trend of cold indices was not. The increase of the maximum and minimum temperatures was most pronounced during summer. Consequently, in the summer season, the MCWD had the largest increase and the MCCN largest decline. Statistically significant increasing trend of the GSL in all stations indicates the extension of favorable weather conditions over Serbia that particularly can benefit crop and pasture yields.

Since duration of the extreme weather conditions described by the MCWD and MCCN is more pronounced during the summer and winter months, respectively, the trends of MCWD and MCCN values for these periods are the best indicators of changes in extreme thermal conditions. Their spatial distributions are presented in Fig. 2. A statistically significant increase of MCWD is observable in all stations. Decrease of MCCN can be noticed in almost all stations, but it was not statistically significant.

3.2 Annual and seasonal changes in precipitation sums and extreme precipitation indices

As was the case for temperature, the decadal trends for precipitation sum and indices are listed in the Table 4. Precipitation sum (R) and RX5day suggest that, in a majority of cases (70–80 %), both the amount and the intensity of precipitation were increasing. Changes in CWD and CDD further reinforce this pattern, with 70 % of stations having an increasing trend in CWD and decreasing trend in CDD. However, the trend line of CWD and CDD is not statistically significant. The most pronounced increase in R and RX5d was recorded in the north and the west of the country, where it was, in most cases, statistically significant.

Trends of precipitation sum and investigated indices were statistically significant only during autumn, indicating the increase in the amount, intensity, and duration

Table 6 Statistically significant seasonal correlation coefficients between the original series of extreme indices and the East Atlantic (EA) index during all seasons, the North Atlantic Oscillation (NAO) index, and the East Atlantic/West Russia (EAWR) index during winter

	Spring	Summer	Autumn	Winter		
	EA	EA	EA	EA	NAO	EAWR
WSDI	–	0.441[a]	–	0.471[a]	–	–
CSDI	–	–	–	–	−0.305[b]	–
MCWD	0.337[b]	0.558[a]	0.265[b]	0.519[a]	0.275[a]	–
MCCN	–	−0.365[a]	–	−0.317[b]	−0.317[b]	–
RX5day	–	–	–	–	–	−0.327[b]
CDD	–	–	–	–	–	–
CWD	–	–	–	–	–	–
WD	0.403[a]	0.590[a]	0.360[a]	0.548[a]	0.395[b]	–
WW	–	0.437[a]	–	0.348[b]	–	–
CD	−0.297[b]	−0.506[a]	−0.366[a]	−0.377[a]	−0.313[b]	–
CW	−0.246[c]	–	−0.463[a]	−0.358[a]	−0.358[a]	–

[a] Statistical significance at the 99 % level ($p<0.01$)

[b] Statistical significance at the 95 % level ($0.01\leq p<0.05$)

[c] Statistical significance at the 90 % level ($0.05\leq p<0.10$)

Table 7 Statistically significant seasonal correlation coefficients between the decadal moving averages of extreme indices and the East Atlantic (EA) index during all seasons, the North Atlantic Oscillation (NAO) index, and the East Atlantic/West Russia (EAWR) index during winter

	Spring	Summer	Autumn	Winter		
	EA	EA	EA	EA	NAO	EAWR
WSDI	0.475[a]	0.963[a]	0.490[a]	0.758[a]	0.730[a]	−0.620[a]
CSDI	0.277[c]	–	0.371[a]	–	0.285[c]	−0.449[a]
MCWD	0.787[a]	0.961[a]	0.396[a]	0.862[a]	0.829[a]	0.871[a]
MCCN	0.362[b]	−0.935[a]	–	0.466[a]	0.403[a]	−0.566[a]
RX5day	0.311[c]	–	0.541[a]	0.307[c]	–	–
CDD	–	−0.324[b]	–	–	–	–
CWD	0.440[a]	0.635[a]	–	−0.423[a]	−0.467[a]	−0.295[c]
WD	0.703[a]	0.933[a]	0.505[a]	0.809[a]	0.904[a]	−0.720[a]
WW	0.787[a]	0.755[a]	0.481[a]	–	–	–
CD	−0.685[a]	−0.860[a]	–	–	–	–
CW	−0.635[a]	−0.600[a]	–	0.686[a]	−0.769[a]	0.576[a]

[a] Statistical significance at the 99 % level ($p<0.01$)

[b] Statistical significance at the 95 % level ($0.01\leq p<0.05$)

[c] Statistical significance at the 90 % level ($0.05\leq p<0.10$)

of rainfall. However, distribution and amount of precipitation are especially important during the growing season, particularly in spring and summer. Although the annual number of dry days averaged over Serbia is decreasing, in some parts of Serbia, CDD tends to rise during spring and summer, which can have a negative impact on agriculture. The spatial distributions of CDD shown in the Fig. 3 indicate that the risk of drought increases in the northern and eastern regions of Serbia during spring and in the central and southern regions during summer.

3.3 Annual and seasonal changes in combined temperature and precipitation indices

Figure 4 provides changes in threshold excess for the four joint temperature and precipitation regimes (WD, WW, CD, and CW), expressed in days per year, that have occurred in the period 1961–2010 in Serbia. It is noticeable that regimes of dry weather in Serbia are much more common than the regimes of wet weather. If we consider only the "dry" regimes, from Fig. 4, we can see that in the first decades of the observed period "dry/cold" regimes dominate, and since the 1980s, the "dry/warm" regimes have become more common. Analyzing the "wet" regimes, the domination of the "cold/wet" regime throughout the observed period is apparent.

Table 5 shows that warm regimes have had an increasing annual trend, while cold regimes have had a decreasing trend. The trends are statistically significant in most stations and seasons. Although joint temperature and precipitation regimes mimic the trends of average temperature, temperature and its evolution is not the exclusive driver of change. Statistically significant autumn trends of both wet regimes tend to rise, which is caused by significant increase of autumn precipitation.

3.4 Relationships between extreme indices and large-scale atmospheric pattern

This section gives an overview of correlation between the examined extreme indices and the large-scale circulation patterns. Considering that annual flows of analyzed variables show significant variations, as clearly visible in the Fig. 5a, we examined the original series and decadal moving average series.

The original series show connections between the EA index and the temperature duration-based indices and combined indices during all seasons. According to Table 6, the summer correlation of WSDI and MCWD with the EA index was positive, while a negative one was found for MCCN. Similar results for correlation of WSDI, MCWD, and MCCN with the EA index were obtained for the winter and for MCWD for the spring and autumn. The original series also show that duration of cold spells and combined cold regimes was negatively correlated with the NAO index during winter, while MCWD was positively correlated, reflecting the relationship with warm conditions in Serbia. The negative correlation of RX5day with the EAWR pattern during

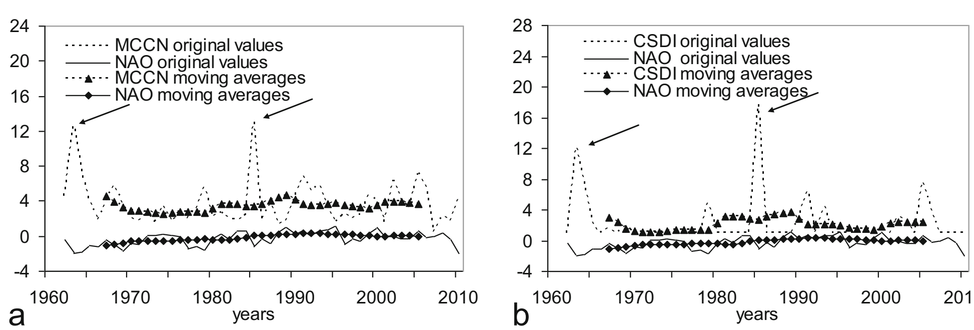

Fig. 6 Original and decadal moving average time series of NAO and MCCN (**a**) and NAO and CSDI (**b**) in winter. *Arrows* show peaks in MCCN and CSDI time series

the winter reflects the relationship with drier conditions, which is caused by penetration of air from western Russia into the Balkan Peninsula.

Higher coefficient values with moving averages confirm results with original time series, especially for variables with pronounced trends. In few cases, the correlation for temperature indices and EA in summer and winter reached values more than 0.90 (Table 7). Comparing the obtained values for original and moving averages, there are opposite signs of relations in few cases, as for winter correlations between NAO and indices which indicate cold periods (MCCN and CSDI) (Table 7). This is due to nonsignificant trends of MCCN and CSDI with some extreme values which could significantly affect the results (marked peaks on Fig. 6a, b). Also, the same explanation is for correlation in winter between EA and MCCN, but also for EA and CW in the same season (Table 7). Therefore, the analysis with moving averages gives better results.

According to analysis of both series, it can be concluded that the weather regimes that bring warm air from south are the main reasons for the increase in the duration of warm periods. It is evident that the positive phase of EA caused longer duration of warm periods and combined warm regimes. However, the impact of EA on the duration of cold periods cannot be confirmed with certainty, except during summer. Besides EA, the NAO was found to have a significant influence on the duration of winter warm periods, while its influence on cold periods cannot be certainly confirmed.

4 Conclusions

This study represents an addition to previous studies of extreme weather conditions with the aim of better understanding the climate change tendency in Serbia. We analyzed the 50-year change in the duration of extreme temperature and precipitation conditions, short-term precipitation intensity and trends of combined temperature and precipitation regimes. Many of the results obtained suggest that the trends in the extreme daily weather variables are consistent with the observations made in the majority of the European countries.

It has been found that time periods of extremely hot weather last longer, while the periods of extremely cold weather are shortened. These trends of duration of extreme temperature conditions are most pronounced in summer season. We found that amount, intensity, and duration of precipitation had statistically significant increase only during the autumn. The most pronounced increase in daily amount and short-term precipitation intensity was recorded in the north and the west of the country. On an average, there was no significant decrease in the maximum number of consecutive dry days or increase in the wet days. Investigation of four combined temperature-precipitation regimes showed the domination of dry regimes over wet, increasing trend of warm regimes and decreasing trend of cold regimes. The correlation between the examined extreme indices and the large-scale circulation patterns showed that weather regimes that bring warm air from south are the main reasons for the increase in the duration of warm periods, increase of combined warm regimes during all seasons and reduction of cold regimes during the summer. Besides EA, the NAO was found to have a significant influence on the duration of winter warm periods, while its influence on cold periods cannot be certainly confirmed.

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