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CHANGES IN EXTREME CLIMATE INDICES IN SARAJEVO (BOSNIA AND HERZEGOVINA)

Abstract: The study analyzes trends in extreme climate indices in Sarajevo (Bosnia and Herzegovina). Based on daily maximum temperatures, daily minimum temperatures and daily precipitation during the 1961–2016 periods, a set of 27 indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection and Indices (ETCCDI) was calculated in the RClimDex (1.0) software. Given the results, the extreme temperature indices displayed a warming tendency throughout the year (most prominent in summer). The positive trends in warm temperature indices were stronger than the downward trends in cold ones. The highest trend values were estimated for TXx, TNx, TX90p, TN90p, WSDI, SU25 and SU30. The extreme precipitation indices displayed trends mixed in sign (annually and seasonally), but all statistically insignificant. However, upward trends in R99p, RX1day, RX5day, SDII, R10mm and R20mm suggest an increase in the magnitude and frequency of intense precipitation events. Moreover, significant changes in distribution of majority temperature indices were determined, whereas shifts in precipitation indices were mostly insignificant. The observed changes in extreme temperature indices are related with large-scale atmospheric circulation patterns (primarily the East-Atlantic pattern) and the Atlantic Multidecadal Oscillation. The negative correlation with the North Atlantic Oscillation, the East Atlantic/West Russia pattern and the Arctic Oscillation is found for majority of extreme precipitation indices.

Key words: extreme temperatures and precipitation indices, trend, Generalized Extreme Value distribution, climate change, Sarajevo (Bosnia and Herzegovina)

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Introduction

Understanding changes in extreme climate events is of a great importance because of their disproportionate large impact on both society and ecosystems compared to the changes in mean climate (Hartmann et al., 2013). A large majority of global land areas had experienced increases in warm temperature indices and decreases in cold ones, since the middle of the 20th century, consistent with the climate system warming (Hartmann et al., 2013). Global scale studies showed that all extreme temperature-related indices displayed a significant warming trend (Alexander et al., 2006; Donat et al., 2013; Morak et al., 2013). Mostly upward trends were also found for the absolute warmest and coldest temperatures of the year – the coldest night (TNn) and coldest day (TXn) of the year, as well as the warmest night (TNx) and the warmest day (TXx) (Alexander et al., 2006; Donat et al., 2013). Globally, waiting period for extreme annual TNn and TXn events that were expected to recur once every 20 years in the 1960s are now estimated to exceed 35 and 30 years, respectively (Zwiers et al., 2011). In contrast, waiting periods for TNx and TXx have decreased to fewer than 10 and 15 years, respectively (Zwiers et al., 2011). Analysis of percentile-based indices showed that the frequency of cold nights and cold days significantly decreased, whereas frequency of warm nights and days increased (Kiktev et al., 2003; Alexander et al., 2006; Donat et al., 2013). A tendency toward shorter cold spells duration and, conversely, longer warm spells duration was determined in most areas associated with the warming (Alexander et al., 2006; Donat et al., 2013). However, the observed trend in warm spell was much greater in magnitude (related to a dramatic rise in WSDI since 1980 or the early 1990s) (Alexander et al., 2006). Globally averaged, WSDI has increased by approximately 8 days since the middle of the 20th century (Donat et al., 2013). Dominant trends in threshold-based indices – the significant positive trends in the annual number of tropical nights and summer days and the negative ones in frost days and icing days also confirm that climate system warming is globally present (Alexander et al., 2006).

IPCC has reported that substantial increases were found in annual heavy precipitation events (disproportionately high compared to changes in mean precipitation) over many mid-latitude areas in the Northern Hemisphere (Hartmann et al., 2013). Global scale studies suggest that, in general, changes in precipitation extremes are consistent with a wetter climate (Alexander et al., 2006; Donat et al., 2013; Hartmann et al., 2013). However, although a general increase in the extreme precipitation indices was found, they showed less spatially coherent patterns of change and weak and mainly insignificant trends (Kiktev et al., 2003; Alexander et al., 2006). Most of the extreme precipitation indices (e.g. R95p, RX5day, SDII, R10mm) displayed changes toward more intense precipitation over numerous regions of the world (Frich et al., 2002; Kiktev et al., 2003; Alexander et al., 2006; Donat et al., 2013). Globally, there has been a steady decline in consecutive dry days (CDD) since the 1960s (Frich et al., 2002; Alexander et al., 2006), which also suggests wetter conditions. Over much of Eurasia, duration of dry spells was also shortened (Kiktev et al., 2003; Donat et al., 2013).

Results of these global studies on extreme temperature and precipitation indices were confirmed by numerous regional and local researches in all parts of the world (Peterson et al., 2008; Aguilar et al., 2009; Andrade et al., 2012; Mouhamed et al., 2013; Sheikh et al., 2015; Yu & Li, 2015; Filahi et al., 2016; Libanda et al., 2017; Santos & de Oliveira, 2017). Globally observed trends in extreme temperature indices have also been confirmed in

Europe (Klein Tank & Können, 2003; Andrade et al., 2012;). The frequency and/or intensity of heavy precipitation have also increased (Hartmann et al., 2013). Averaged at the continental level, most of the extreme precipitation indices (R95p, R10mm, R20mm and RX5day) increased significantly (only increase in RX1day was insignificant) since the middle of the 20th century (Klein Tank & Können, 2003). However, the spatial coherence of the trends was also much weaker than for the extreme temperature indices (Klein Tank & Können, 2003). The warming trend and weak extreme precipitation trends mixed in sign have also been reported by the previous studies in the part of the continent where Sarajevo (Bosnia and Herzegovina) is located (Unkašević & Tošić, 2011; Unkašević & Tošić, 2013; Branković et al., 2013; Burić et al., 2014; Zaninovic & Cindric, 2014; Burić et al., 2015; Gajić-Čapka et al., 2015; Malinovic-Milicevic et al., 2016; Milošević et al., 2017).

This study is a continuation of the research on climate change in Bosnia and Herzegovina (Trbić et al., 2017), and in particular on extreme climate events (Popov et al., 2017a; Popov et al., 2017b; Popov et al., 2018). The main aim of this study was: to compute extreme temperature and precipitation indices for Sarajevo area during the 1961–2016 periods; to analyze trends and changes in distributions of extreme climate indices and to evaluate the relationship between observed changes in extreme climate indices and the large-scale circulation patterns over the Northern Hemisphere.

Material and methods

The selected area for studying climate change in Bosnia and Herzegovina is Sarajevo region, located in the central mountainous part of Bosnia and Herzegovina, in the Miljacka River and Bosna River valleys, at an altitude of 630 m, surrounded by the Romanija, Trebević, Jahorina, Igman, Treskavica and Bjelašnica Mountains. Sarajevo lies in the middle part of the northern temperate zone, at 43°52´04˝ N latitudes and 18°25´22˝ E longitudes.

The analysis of extreme temperature and precipitation indices during the 1961–2016 periods was carried out using climatological data set of daily maximum temperatures (Tmax), daily minimum temperatures (Tmin) and daily precipitation (R) from Sarajevo meteorological station. Data were provided by the Federal Hydrometeorological Institute Sarajevo. During the observed period meteorological station did not change location and there were no interruptions in measurements. However, before calculations, basic data quality control procedure in RClimDex was performed. The few outliers (determined as values outside a range of four standard deviations of the climatological mean value for that day) were found and manually checked and confirmed. Further, homogeneity of the input data series has been tested using RHtestsV4 (Wang & Feng, 2013a) and RHtests_dlyPrcp (Wang & Feng, 2013b). The RHtestsV4 software package was used to detect multiple changepoints (i.e. breaks, shifts) that could exist in maximum and minimum temperatures data series that may have first order autoregressive errors. It is based on the penalized maximal F test (Wang, 2008b), which are embedded in a recursive testing algorithm (Wang, 2008a). Homogeneity of daily precipitation data time series was investigated using the RHtests_dlyPrcp software package based on the transPMFred algorithm (Wang et al., 2010), which integrates a data adaptive Box-Cox transformation procedure (that is necessary because daily precipitation are not normally distributed) into the PMFred algorithm (Wang, 2008a). The results of data homogeneity testing showed that there were no significant changepoints in Tmax, Tmin and R time series.

Basic statistical parameters of input variables used in the study are given in Tab. 1. The average annual and seasonal values of input variables are displayed in Tab. 2. The annual Tmax and Tmin in Sarajevo area are 15.6 °C and 5.3 °C, respectively. Summer is the warmest season (25.8 °C and 12.9 °C, respectively), whereas winter being the coldest (4.4 °C and -2.7 °C, respectively). Autumn is warmer than spring (16.3 °C and 6.0 °C vs. 15.7 °C and 4.8 °C, respectively). Mean annual precipitation in the observed 1961–2016 periods is 943 mm. Precipitation is relatively evenly distributed throughout the year. Maximum precipitation occurs in autumn (259 mm or 27 % of annual total).

Tab. 1. Statistical parameters of the input variables time series in the 1961–2016 periods

Variable	Mean (mm)	Maximum (mm)	Minimum (mm)	Standard deviation (mm)	Skewness	Kurtosis
Tmax	15.6	17.4	14.0	0.9	0.330	-0.837
Tmin	5.3	7.3	4.2	0.7	0.733	-0.091
R	943	1249	626	146	-0.211	-0.611

Tab. 2. Annual and seasonal mean values of the input variables in the 1961–2016 periods

Variable	Winter	Spring	Summer	Autumn	Year
Tmax	4.4	15.7	25.8	16.3	15.6
Tmin	-2.7	4.8	12.9	6.0	5.3
R	226	228	234	259	943

During the observed period, Tmax and Tmin showed significant upward annual and seasonal trends (only insignificant for Tmax in autumn) (Tab. 3). The annual Tmax and Tmin increased for 0.42 °C per decade and 0.32 °C per decade, respectively. Although positive trends were present throughout the year, the warming tendency was most prominent in summer season (0.66 °C per decade and 0.42 °C per decade, respectively) and then in winter and spring. In contrary to the coherent temperature trends, precipitation displayed trends mixed in sign (increase in spring and autumn and decrease in winter and summer), but all statistically insignificant (Tab. 3). Annual precipitation showed only slight and insignificant positive trend in the range of 1.68 mm per decade.

Tab. 3. Decadal trends in the input variables in the 1961–2016 periods

Var.	Winter		Spring		Summer		Autumn		Year	
	S	p-value	S	p-value	S	p-value	S	p-value	S	p-value
Tmax	0.41	0.0071	0.40	0.0017	0.66	0.0000	0.17	0.2008	0.42	0.0000
Tmin	0.46	0.0016	0.23	0.0023	0.42	0.0000	0.23	0.0139	0.32	0.0000
R	-5.79	0.5712	4.15	0.4003	-2.86	0.5766	4.22	0.5201	1.68	0.9493

Note: Var – Variable; S - Slope

A set of 15 extreme temperature indices and 10 extreme precipitation indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection and Indices (ETCCDI) was chosen for the analysis of recent climate extremes variability over the study area. In addition, two more indices have been calculated – SU30 and R1mm.

Therefore, a total of 27 indices (Tab. 4) were used for climate change analysis in the Sarajevo area.

Tab. 4. Definitions of the indices used in the study (ETCCDI, 2009)

Index	Descriptive name	Definition	Units
EXTREME TEMPERATURE INDICES			
TXx	Maximum value of daily maximum temperature	Annual maximum value of TX	°C
TXn	Minimum value of daily maximum temperature	Annual minimum value of TX	°C
TNx	Maximum value of daily minimum temperature	Annual maximum value of TN	°C
TNn	Minimum value of daily minimum temperature	Annual minimum value of TN	°C
TX10p	Cold days	Number of days when TX < 10th percentile	days
TX90p	Warm days	Number of days when TX > 90th percentile	days
TN10p	Cold nights	Number of days when TN < 10th percentile	days
TN90p	Warm nights	Number of days when TN > 90th percentile	days
ID0	Icing days	Annual count of days when TX < 0°C	days
FD0	Frost days	Annual count of days when TN < 0°C	days
SU25	Summer days	Annual count of days when TX > 25°C	days
SU30	Tropical days	Annual count of days when TX > 30°C	days
TR20	Tropical nights	Annual count of days when TN > 20°C	days
WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when TX > 90th percentile	days
CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days when TN < 10th percentile	days
GSL	Growing season length	Annual (1st Jan to 31st Dec in Northern Hemisphere) count between first span of at least 6 days with daily mean temperature > 5°C and first span after July 1st of 6 days with < 5°C	days
EXTREME PRECIPITATION INDICES			
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation in days when precipitation >=1mm	mm
RX1day	Highest 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Highest 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple precipitation intensity index	Annual total precipitation divided by the number of wet days in the year	mm/day
R1mm	Wet days	Annual count of days when precipitation >=1mm	days
R10mm	Heavy precipitation days	Annual count of days when precipitation >=10mm	days
R20mm	Very heavy precipitation days	Annual count of days when precipitation >=20mm	days
R95p	Very wet days	Annual total precipitation when daily precipitation >95th percentile	mm
R99p	Extremely wet days	Annual total precipitation when daily precipitation >99th percentile	mm
CDD	Consecutive dry days	Maximum number of consecutive days with daily precipitation <1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with daily precipitation >=1mm	days

The selected indices cover a few different categories (Alexander et al., 2006):

- Absolute indices that represent total, maximum or minimum values within a year (TNx, TNn, TXx, TXn, PRCPTOT, RX1day, RX5day and SDII).
- Percentile-based indices (TN10p, TX10p, TN90p, TX90p, R95p and R99p). The 1961–1990 periods was set as the base period for determining the frequency distribution for these indices.
- Absolute-based (fixed) threshold indices defined as the number of days on which a temperature or precipitation value falls above or below a fixed threshold (FD0, ID0, SU25, SU30, TR20, R1mm, R10mm and R20mm).
- Duration-based indices defined as periods of the excessive warmth and cold in the case of temperature or the excessive dry and wet periods in the case of precipitation (WSDI, CSDI, GSL, CDD and CWD).

An overview of the average annual values of the extreme climate indices used in the study during the observed period (1961–2016) is given in Tab. 5.

Tab. 5. Average values of extreme climate indices in the 1961–2016 periods

Index	Value	Index	Value	Index	Value
TXx	34.64	FD0	89.32	RX5day	84.20
TXn	-6.79	SU25	72.02	SDII	8.10
TNx	19.78	SU30	20.68	R1mm	113.89
TNn	-14.94	TR20	0.64	R10mm	31.25
TX10p	34.88	WSDI	11.86	R20mm	9.70
TX90p	51.13	CSDI	4.32	R95p	200.53
TN10p	33.31	GSL	266.70	R99p	60.92
TN90p	49.65	PRCPTOT	924.73	CDD	22.20
ID0	23.34	RX1day	50.22	CWD	6.95

The extreme climate indices were calculated using RClimDex (1.0) software package that had been developed at the Climate Research Division Canada (Zhang & Yang, 2004). Trend slopes estimate and its statistical significance were also computed in RClimDex by linear least square method and locally weighted linear regression (Zhang & Yang, 2004). Changes in extreme climate indices distributions were further examined. The nonparametric Kolmogorov–Smirnov test was used to analyse changes in probability distributions of the indices between two periods – the 1961–1990 periods and the 1991–2016 periods. Test was performed in XLSTAT Version 2014.5.03. Maximum likelihood estimation (MLE) method was used for estimating the Generalized Extreme Value (GEV) distribution parameters of annual maximum Tmax, Tmin and R. R package 'extRemes' was used for performing extreme value analysis (Gilleland & Katz, 2016). In order to evaluate the observed changes in extreme climate indices, the relationships with the large-scale atmospheric circulations patterns over the Northern Hemisphere – the North Atlantic Oscillation (NAO), the East-Atlantic (EA) pattern, the East Atlantic/West Russia (EAWR) pattern and the Arctic Oscillation (AO) (Barnston & Livezey, 1987; Thompson & Wallace, 1998) – were investigated. Data on these patterns indices were collected from NOAA Climate Prediction Center (NOAA CPC, 2017). For relationship quantification, the Pearson correlation coefficients were calculated in XLSTAT Version 2014.5.03.

In addition to these large-scale atmospheric circulation patterns, influence of the Atlantic Multidecadal Oscillation (AMO) on the extreme climate indices over the study area was also analyzed. Its impact on temperature indices was primarily investigated, as earlier studies have determined that the AMO index is positively correlated with the global mean annual surface land temperature (Muller et al., 2013). Since the mid-19th century, when instrumental measurements started, the AMO (i.e. sea surface temperature variability in the North Atlantic) showed two 65–80 years cycles with a 0.4 °C amplitude between extremes of positive/warm and negative/cool phases (Gray et al., 2004).

Results and Discussion

Analysis of the observed changes in extreme climate indices

The decadal trends in annual extreme temperature indices in the 1961–2016 periods are given in Tab. 6. The absolute temperature indices (TXx, TXn, TNx and TNn) displayed the significant positive trends during the observed periods (only TXn trend was statistically insignificant). Although all indices showed upward trends, the estimated trend values for maximum values of daily maximum and minimum temperatures – TXx and TNx (0.76 °C per decade and 0.53 °C per decade, respectively) were much higher than those in minimum values of daily maximum and minimum temperatures – TXn and TNn (0.29 °C per decade and 0.45 °C per decade, respectively).

Tab. 6. Decadal trends in annual extreme temperature indices in the 1961–2016 periods

Index	TXx	TXn	TNx	TNn	TX10p	TX90p	TN10p	TN90p
Slope	0.76	0.29	0.53	0.45	-3.28	9.66	-4.58	8.20
p-value	0.000	0.105	0.004	0.053	0.000	0.000	0.000	0.000
Index	ID0	FD0	SU25	SU30	TR20	WSDI	CSDI	GSL
Slope	-2.45	-3.54	6.25	5.91	0.19	6.39	-0.36	3.40
p-value	0.000	0.006	0.000	0.000	0.043	0.000	0.522	0.161

Trends in percentile-based temperature indices – the significant upward trends in annual number of warm days (TX90p) and warm nights (TN90p) as well as the significant downward trends in annual number of cold days (TX10p) and cold nights (TN10p) – also suggest that climate system warming is present over the study area. However, the increase in TX90p (9.66 days per decade) and TN90p (8.20 days per decade) was much higher than the decline in TX10p (-3.28 days per decade) and TN10p (-4.48 days per decade).

The estimated trends in threshold-based temperature indices were also as expected in a warmed climate system – warm temperature indices showed the significant positive trends, whereas cold temperature indices displayed the downward trends. The positive trends in SU25 and SU30 (6.25 days per decade and 5.91 days per decade, respectively) were much more prominent than the negative ones in cold temperature indices ID0 and FD0 (-2.45 days per decade and -3.54 days per decade, respectively). The occurrence of TR20 was very rare. Only 1 or 2 such days have usually been recorded annually (however, during the intense heat wave in 2007 even 7 tropical nights occurred).

It should be noted that, during the observed 1961–2016 periods, warm spell duration has significantly increased (a highly prominent positive trend was in the range of 6.39

days per decade), whereas cold spell duration was slightly shortened (for just -0.36 days per decade). The increasing maximum and minimum temperatures led to extension of the growing season length by 3.40 days per decade (although still insignificant).

The decadal trends in extreme temperature indices calculated seasonally (Tab. 7) indicated that warming trend was present throughout the year. The seasonal absolute temperature indices showed that an upward trend was apparent in all seasons, but most prominent was in summer and then in spring and winter (except for TNn). The highest trend values were estimated for maximum values of Tmax and Tmin – for TXx 0.80 °C and 0.82 °C per decade in summer and spring, respectively, and for TNx 0.57 °C and 0.50 per decade in summer and winter, respectively. The percentile-based indices displayed similar patterns of change throughout the year. The highest seasonal increase/decrease in number of warm/cold days and nights occurred in the warmest season. In this part of the year, TX90p and TN90p displayed the particularly prominent positive trends – in the range of 4.95 days per decade and 4.28 days per decade, respectively.

Tab. 7. Decadal trends in seasonal extreme temperature indices in the 1961–2016 periods

Variable	Winter		Spring		Summer		Autumn	
	Slope	p-value	Slope	p-value	Slope	p-value	Slope	p-value
TXx	0.29	0.0727	0.82	0.0000	0.80	0.0000	0.15	0.4161
TXn	0.27	0.1766	0.09	0.7077	0.39	0.0501	0.12	0.5861
TNx	0.50	0.0179	0.04	0.8485	0.57	0.0003	0.50	0.0017
TNn	0.40	0.1184	0.52	0.0681	0.32	0.0020	0.46	0.0845
TX10p	-0.75	0.1609	-0.83	0.0404	-1.11	0.0008	0.08	0.7558
TX90p	1.21	0.0123	1.80	0.0025	4.95	0.0000	1.20	0.0139
TN10p	-0.77	0.1526	-0.82	0.0150	-1.66	0.0000	-0.39	0.2825
TN90p	1.28	0.0057	0.81	0.0726	4.28	0.0000	1.20	0.0279

In contrast to the coherent significant warming tendency determined for the extreme temperature indices, trends in extreme precipitation indices were not uniform (homogenous). However, the obtained results indicate a general increase in amount, intensity and variability of the extreme precipitation. Although, all the estimated trend values were not statistically significant. Decadal trends in annual extreme precipitation indices are shown in Tab. 8.

Annual total precipitation in wet-days (PRCPTOT) displayed a very weak positive trend during the observed period (2.04 mm per decade). The maximum annual daily precipitation amount (RX1day) has slightly increased during the observed periods (0.68 mm per decade), whereas the increase in the maximum consecutive 5-day precipitation amount (RX5day) was somewhat higher (1.47 mm per decade), but still insignificant. Simple precipitation intensity index (SDII) showed upward trend in the range of 0.07 mm/days. The analysis of threshold-based precipitation indices showed presence of trends mixed in sign. The estimated negative trend in annual number of wet days (R1mm) was in the range of -0.86 days per decade. The upward trends in annual numbers of heavy precipitation days (R10mm) and very heavy precipitation days (R20mm) (in the range of 0.23 and 0.17 days per decade, respectively) suggest changes toward more intense precipitation. The decadal trends in percentile-based indices showed that the contribution from very wet days to the annual precipitation total (R95p) declined (-2.26 mm per decade), whereas the contribution from extremely wet days (R99p) increased much more (4.92 mm per decade). Duration-based indices, maximum number of consecutive dry days (CDD) and consecutive wet days CWD), displayed almost negligible negative trends – in the range of -0.12 and -0.05 days per decade, respectively.

Tab. 8. Decadal trends in annual extreme precipitation indices in the 1961–2016 periods

Index	Slope	p-value
PRCPTOT	2.04	0.867
RX1day	0.68	0.623
RX5day	1.47	0.424
SDII	0.07	0.256
R1mm	-0.86	0.437
R10mm	0.23	0.662
R20mm	0.17	0.486
R95p	-2.26	0.763
R99p	4.92	0.320
CDD	-0.12	0.821
CWD	-0.05	0.723

The extreme precipitation indices calculated seasonally – RX1day and RX5day – showed that trends mixed in sign were present throughout the year (Tab. 9). However, all of the estimated trends were not statistically significant.

Although global scale studies (Alexander et al., 2006) and studies in Europe at continental level (Klein Tank & Können, 2003) demonstrated stronger warming trends for Tmin than for Tmax in Sarajevo region changes in maximum temperatures were more prominent (0.42 °C per decade vs. 0.32 °C per decade). However, stated follows the results of other studies in the Southeast Europe region (Branković et al., 2013; Burić et al., 2015; Malinovic-Milicevic et al., 2016). The trends in the extreme temperature indices obtained in this study are generally in accordance with the results of previous studies carried out in this region (Branković et al., 2013; Unkašević & Tošić, 2013; Zaninovic & Cindric, 2014; Burić et al., 2015; Malinovic-Milicevic et al., 2016; Ruml et al., 2017). The obtained results (both the positive trends in warm temperature indices and the negative trends in cold ones) suggest that the climate system warming was present over the study area. It should be noted that the upward trends in warm temperature indices were much more prominent than the downward trends associated with cold ones. The highest trend values were estimated for TXx, TNx, TX90p, TN90p, WSDI, SU25 and SU30. Analysis of seasonal indices trends demonstrated that the warming was most pronounced in summer season.

Tab. 9. Decadal trends in seasonal extreme precipitation indices in the 1961–2016 periods

Variable	Winter		Spring		Summer		Autumn	
	Slope	p-value	Slope	p-value	Slope	p-value	Slope	p-value
RX1day	-0.71	0.5911	-1.00	0.2322	0.12	0.8597	1.74	0.1166
RX5day	-2.56	0.2199	0.89	0.5670	-0.94	0.6158	1.92	0.2214

The analysis of the extreme temperature indices deviations from the 1961–1990 averages (Fig. 1) confirms that the warming tendency becomes stronger since the beginning of the 21st century. In that period, the warm temperature indices TXx, SU25, SU30 and WSDI registered not a single occurrence below the standard climatological period averages, whereas the TX90p and TN90p displayed only one year below the average (2005). The cold temperature indices were mostly below average, thus confirming the increasing climate system warming.

The 10 warmest years have been recorded after 1990 (only 1994 of them prior to 2000). Among the 10 years with highest/lowest values of warm/cold temperature indices, there were also only a few years prior to 1990 (most of them was recorded in the 21st century). For example, the extremely low/high values of cold/warm temperature indices were observed during the some of the warmest years. The hottest year in the observed 1961–2016 periods was 2014 during which extremely low values of cold temperature indices were recorded – in that year there were only 20 TX10p, 14 TN10p, 5 ID0, 33 FD0 and without a single CSDI. Some of the highest frequencies of warm temperature indices were observed in very warm 2012 with the occurrence of intense heat wave – then even 113 TX90p, 83 TN90p, 116 SU25, 68 SU30 and 70 WSDI was recorded. The average annual value of SU30 tripled and of TX90p and TN90p doubled in the last decade compared to the 1961–1990 periods averages, whereas the annual number of WSDI increased 9-fold. The vast majority of the most intense and long-lasting heat waves since 1951 (Russo et al., 2015) in this part of the continent occurred in the 21st century – in 2003, 2007, 2010, 2012 and 2015.

Changes in the analyzed indices cumulative distributions between the 1961–1990 periods and the 1991–2016 periods are displayed in Fig. 2. The Kolmogorov–Smirnov test results showed that the cumulative distributions of the temperature indices were statistically different in the 1991–2016 periods compared to the 1961–1990 periods (except for FD0, ID0, TNn, TXn, GSL, TR20 and CSDI for which determined changes were insignificant). The cumulative distributions of the warm temperature indices between two periods shifted to the right towards higher values, whereas the cold temperature indices shifted to the left towards lower values.

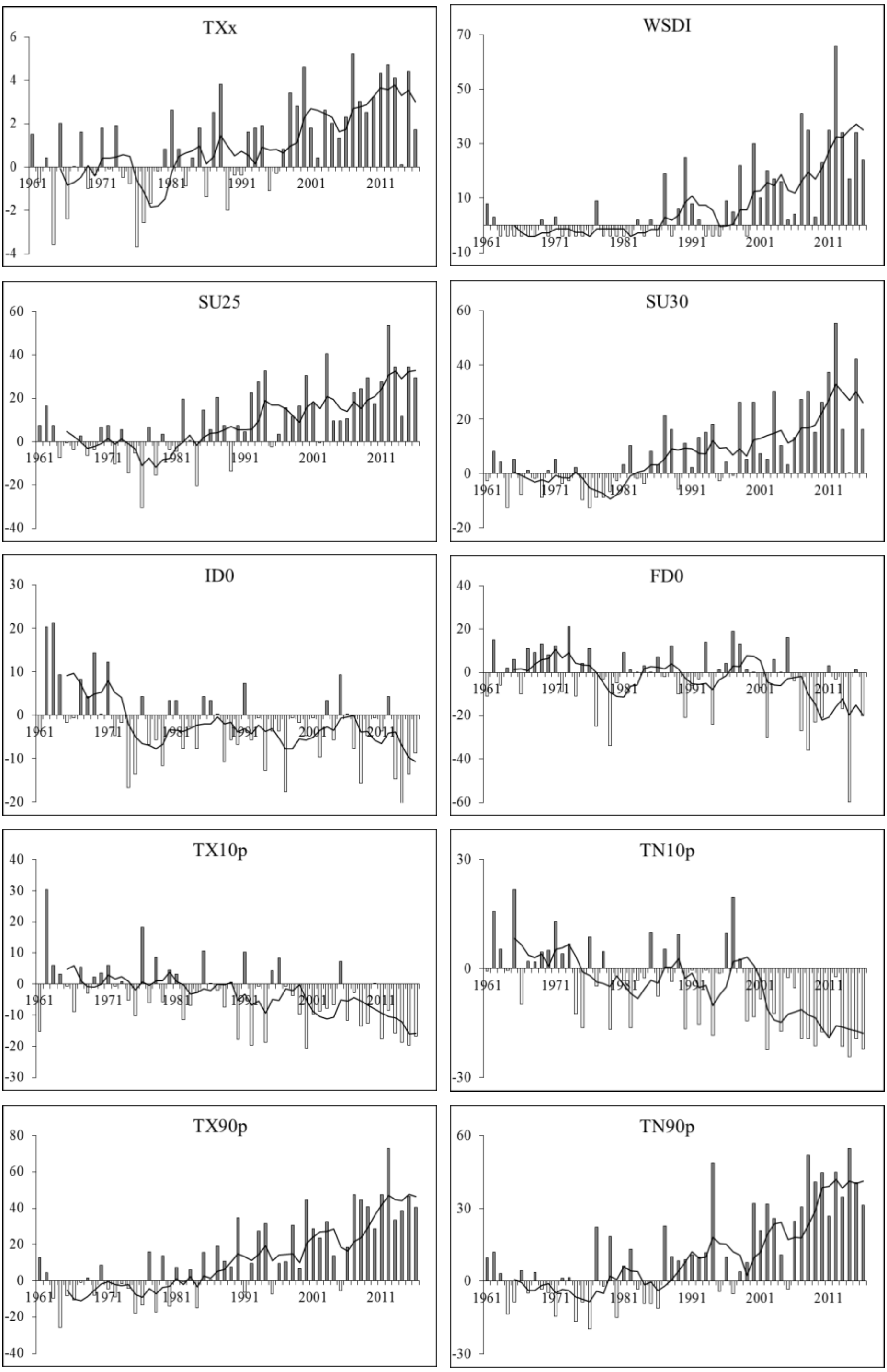

Fig. 1. Annual deviations of the selected extreme temperature indices from the 1961–1990 periods averages (the bold lines represent the 5-year moving averages)

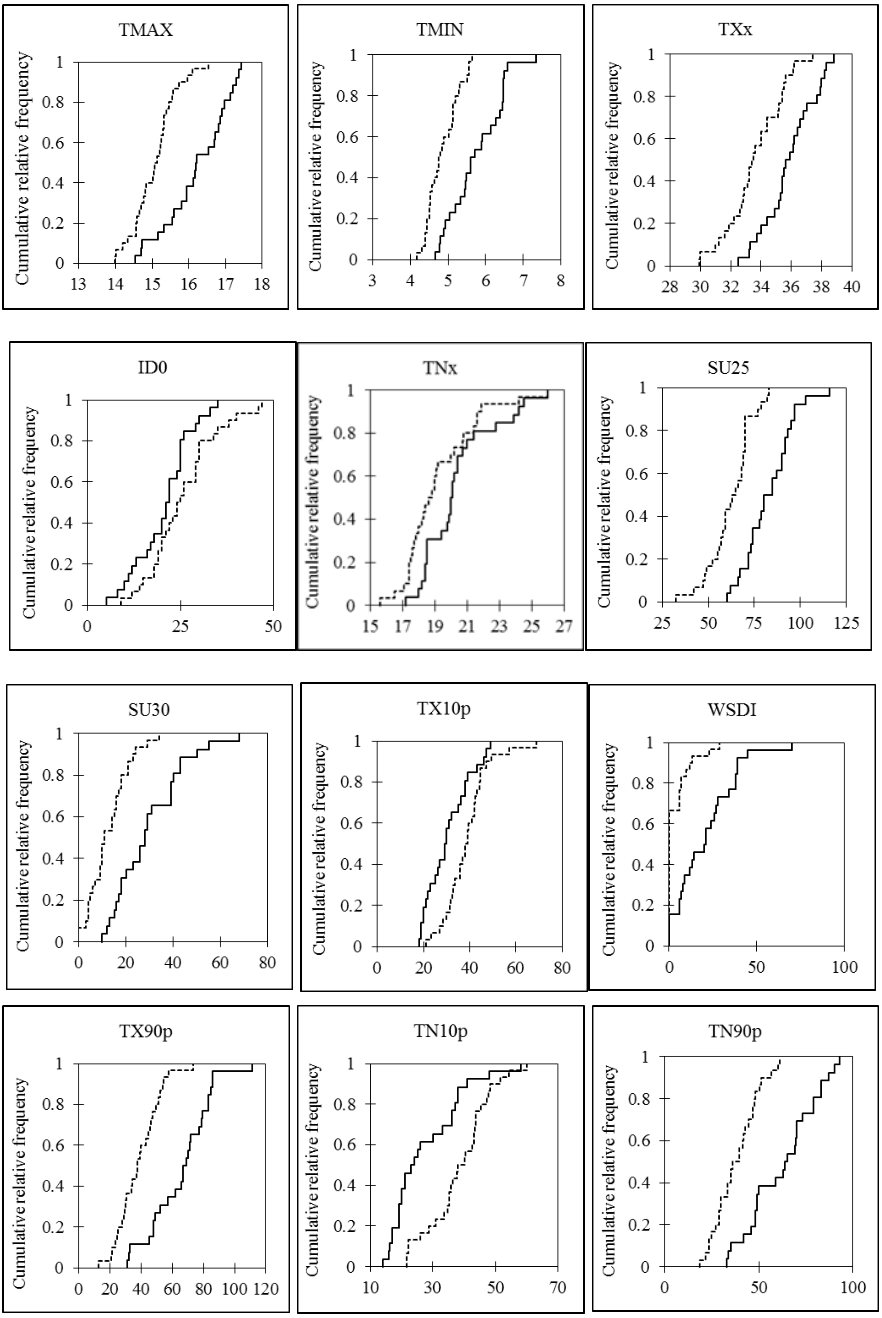

Fig. 2. Changes in cumulative distributions of the selected temperature indices between the 1961–1990 periods (dashed line) and the 1991–2016 periods (solid line)

The analysis of Generalized Extreme Value (GEV) distribution parameters showed increasing values of location parameter for both Tmax and Tmin in the 1991–2016 periods compared to reference period (Tab. 10), which confirms increasing warming trend since the1990s. Lower scale parameter values suggest more concentrated distribution variability in latter period. Moreover, the 2-year and 20-year events of both Tmax and Tmin have become more common since the 1990s. This increase in return levels values was particularly pronounced for Tmax.

Tab. 10. Estimated GEV distribution parameters and return levels fitted to the annual maximum Tmax, Tmin and R in the 1961–1990 and 1991–2016 periods

Parameter	Tmax		Tmin		R	
	1961–1990	1991–2016	1961–1990	1991–2016	1961–1990	1991–2016
Location	32.985	35.385	18.206	19.347	41.621	43.351
Scale	1.860	1.761	1.655	1.561	10.242	9.876
Shape	-0.335	-0.426	0.040	0.093	0.141	0.201
Estimated return levels						
2-year	33.627	35.983	18.818	19.929	45.474	47.108
20-year	36.486	38.353	23.427	24.684	79.421	83.508

In contrary to the coherent and significant trends in extreme temperatures, extreme precipitation indices displayed mainly weak, insignificant and mixed in sign trends. Further, the Kolmogorov–Smirnov test results have not determined significant changes in the indices distributions (results not shown). The analysis of annual maximum precipitations GEV distribution parameters showed that location parameter only slightly increased in the 1991–2016 periods compared to the reference period, whereas scale parameter value was lower. Although a lower distribution variability has been identified for the latter period, since the beginning of the 20th century, a increase in inter-annual precipitation variability has been noticed – year with precipitation far above the average followed by year with extremely low precipitation or vice versa (e.g. 2000–2001, 2010–2011 and 2014–2015) (Fig. 3). Further, results generally suggest that precipitation intensity has been increasing since the beginning of the 21st century – e.g. increase in the intense precipitation (R99p). The 2-year and 20-year precipitation return levels also increased in that period. Results of previous studies in Bosnia and Herzegovina (Popov et al., 2017b) and other parts of the Southeast Europe region (Unkašević & Tošić, 2011; Gajić-Čapka et al., 2015; Burić et al., 2015) have also found spatially and temporally (seasonally) incoherent (both of sign) and mainly statistically insignificant trends in extreme precipitation indices.

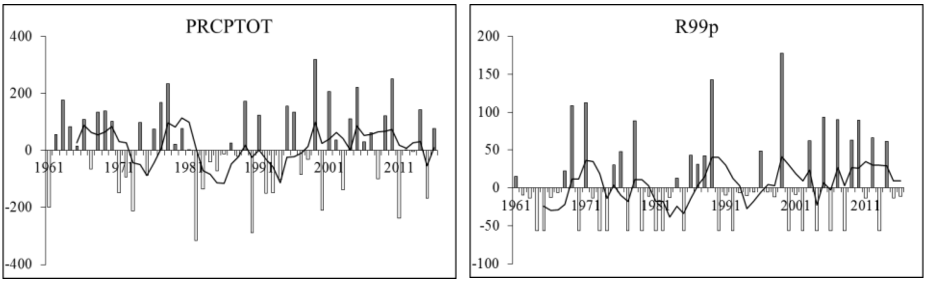

Fig. 3. Annual deviations of the selected extreme precipitation indices from the 1961–1990 periods averages (the bold lines represent the 5-year moving averages)

Relationship between the observed changes in extreme climate indices and the large-scale atmospheric circulation patterns

The observed temperature variability (the warming tendency) was primarily associated with the EA pattern. The positive phase of the EA pattern is associated with above-average temperatures in the part of Europe where Sarajevo (Bosnia and Herzegovina) is located throughout the year (Rust et al., 2015). The significant positive correlation with mean seasonal and annual temperatures in Bosnia and Herzegovina has been previously found in Trbić et al. (2017) research. Results presented in Tab. 11. show that there is also a significant correlation with extreme temperature indices – the positive with the all warm temperature indices and the negative with the cold ones (insignificant only for TXn, TNn and CSDI). The highest correlation coefficients (>0.5) were determined for Tmax and Tmin, and for TX90p, TN90p, TX10p, TN10p, SU25 and WSDI. Table 12 shows that extreme temperature indices are strongly (significantly) dictated by the EA pattern in all seasons. The NAO has somewhat stronger impact on cold temperature indices. Strong positive NAO index since the early 1980s accounted for a substantial part of the observed warming over the continent in winter (Hurrell, Van Loon, 1997). In addition, the AO has a greater impact on extreme temperatures in Sarajevo area in spring season.

Tab. 11. Pearson correlation coefficient between annual teleconnection patterns indices and extreme climate indices in the 1961–2016 periods

Variable	EA	NAO	EAWR	AO	Variable	EA	NAO	EAWR	AO
Tmax	**0.702**	0.103	**-0.357**	**0.293**	WSDI	**0.519**	-0.076	**-0.420**	0.171
Tmin	**0.701**	0.089	**-0.436**	0.227	CSDI	-0.176	-0.259	0.113	-0.194
TXx	**0.478**	-0.137	**-0.313**	0.064	GSL	**0.284**	-0.200	**-0.287**	-0.145
TXn	0.074	**0.323**	-0.121	0.239	R	-0.057	**-0.393**	**-0.287**	**-0.531**
TNx	**0.468**	-0.085	**-0.312**	0.028	PRCPTOT	-0.061	**-0.391**	**-0.288**	**-0.529**
TNn	0.128	**0.293**	-0.096	0.225	RX1day	-0.025	0.029	-0.109	0.012
ID0	**-0.428**	**-0.310**	0.135	**-0.325**	RX5day	-0.047	-0.023	-0.090	-0.091
FD0	**-0.445**	-0.059	**0.356**	-0.062	SDII	0.153	**-0.295**	-0.161	**-0.362**
SU25	**0.611**	-0.049	-0.233	0.159	R1mm	-0.223	**-0.310**	**-0.266**	**-0.453**
SU30	**0.516**	-0.073	**-0.318**	0.187	R10mm	0.047	**-0.416**	**-0.333**	**-0.551**
TR20	**0.268**	-0.056	-0.179	0.059	R20mm	0.046	**-0.309**	-0.259	**-0.342**
TX10p	**-0.636**	-0.253	0.106	**-0.366**	R95p	-0.080	-0.147	-0.235	**-0.271**
TX90p	**0.702**	-0.020	**-0.419**	0.220	R99p	-0.064	-0.001	-0.162	-0.045
TN10p	**-0.598**	-0.187	**0.331**	**-0.263**	CDD	-0.091	0.043	0.130	0.027
TN90p	**0.699**	-0.070	**-0.479**	0.138	CWD	-0.247	0.014	0.101	0.052

Note: Values in bold are statistically significant at $p<0.05$ level

Strong positive phases of the NAO, as well as the EA pattern and the EAWR pattern are generally associated with below-average precipitation over southern and central Europe (NOAA CPC, 2017). The significant negative correlation with these large-scale circulation patterns was found for mean annual precipitation and for majority of the analyzed extreme precipitation indices (Tab. 11). Precipitation have been strongly dictated by the analyzed teleconnection patterns, particularly in winter season. For this part of the year the significant negative correlation was found for the NAO, the EA pattern, the EAWR pattern and the AO (Tab. 12). Further, the AO has a greater impact on precipitation variability in autumn.

Tab. 12. Pearson correlation coefficient between seasonal teleconnection patterns indices and extreme temperature and precipitation indices in the 1961–2016 periods

Variable	Winter				Spring			
	EA	NAO	EAWR	AO	EA	NAO	EAWR	AO
Tmax	**0.709**	0.250	-0.119	0.083	**0.478**	0.144	0.134	**0.363**
Tmin	**0.669**	0.228	-0.219	0.000	**0.419**	0.112	0.040	**0.344**
TN10p	**-0.517**	-0.255	0.027	-0.095	-0.234	-0.119	-0.045	-0.257
TN90p	**0.624**	-0.048	**-0.368**	-0.170	**0.396**	-0.081	-0.032	**0.286**
TX10p	**-0.487**	**-0.335**	-0.049	-0.202	**-0.469**	-0.100	-0.173	-0.244
TX90p	**0.639**	0.089	-0.173	0.019	**0.432**	0.169	0.042	**0.322**
TNn	**0.455**	0.148	-0.046	0.096	0.210	0.258	0.101	**0.359**
TNx	**0.362**	-0.065	**-0.271**	-0.208	0.169	-0.065	-0.127	0.128
TXn	**0.442**	0.213	0.044	0.084	0.119	0.157	-0.035	**0.285**
TXx	**0.615**	0.048	-0.096	0.052	**0.411**	-0.097	-0.111	0.015
R	**-0.273**	**-0.347**	**-0.423**	**-0.594**	-0.011	-0.084	-0.153	-0.208
RX1day	-0.254	-0.111	**-0.307**	-0.205	0.167	-0.014	-0.054	0.025
RX5day	**-0.342**	-0.202	-0.164	-0.253	0.093	0.041	-0.085	0.035
Variable	Summer				Autumn			
	EA	NAO	EAWR	AO	EA	NAO	EAWR	AO
Tmax	**0.669**	**-0.505**	**-0.398**	-0.223	**0.462**	-0.144	-0.151	0.017
Tmin	**0.687**	**-0.464**	**-0.474**	-0.137	**0.439**	-0.155	**-0.283**	-0.200
TN10p	**-0.491**	0.236	**0.305**	0.165	**-0.457**	0.085	**0.347**	0.137
TN90p	**0.665**	**-0.516**	**-0.487**	-0.103	**0.344**	-0.084	-0.166	-0.109
TX10p	**-0.538**	**0.276**	0.171	0.199	**-0.485**	0.058	0.005	0.018
TX90p	**0.648**	**-0.547**	**-0.436**	-0.227	**0.394**	-0.175	-0.166	0.146
TNn	**0.365**	-0.249	**-0.267**	-0.104	**0.339**	-0.127	-0.248	-0.239
TNx	**0.470**	**-0.320**	**-0.589**	-0.058	**0.464**	**-0.277**	-0.075	-0.122
TXn	0.216	-0.261	-0.115	**-0.274**	0.231	-0.128	-0.128	-0.131
TXx	**0.593**	**-0.429**	**-0.424**	-0.162	**0.361**	0.027	-0.109	**0.268**
R	-0.235	0.133	0.019	0.090	-0.197	-0.160	-0.259	**-0.390**
RX1day	-0.134	0.078	-0.153	0.083	-0.073	-0.063	-0.154	-0.074
RX5day	-0.108	0.045	-0.059	-0.082	-0.083	-0.103	-0.095	-0.126

Note: Values in bold are statistically significant at $p<0.05$ level

Relationship between observed temperature changes and the AMO

Since 1990s, when the AMO entered in its warm phase (Alexander et al., 2014), the temperature increase also becomes more pronounced both globally and in Bosnia and Herzegovina (Trbić et al., 2017). Tab. 13 shows that the warm temperature indices are positively and significantly correlated with the AMO. The strongest relation (correlation coefficients > 0.5) was found for WSDI, TX90p, TN90p, SU30, SU25 and TXx. Correlation with cold temperature indices is negative and insignificant. The influence of the AMO on temperatures over the study area is the strongest in summer (significant for Tmax and Tmin and all of the indices except for TXn) and then in autumn (significant for majority of the indices) (Tab. 14).

Tab. 13. Pearson correlation coefficient between annual AMO and extreme temperature indices in the 1961–2016 periods

Variable	AMO	Variable	AMO	Variable	AMO
Tmax	**0.481**	ID0	-0.004	TX90p	**0.553**
Tmin	**0.457**	FD0	-0.180	TN10p	**-0.314**
TXx	**0.500**	SU25	**0.529**	TN90p	**0.552**
TXn	-0.075	SU30	**0.530**	WSDI	**0.591**
TNx	**0.396**	TR20	0.228	CSDI	0.018
TNn	-0.081	TX10p	-0.260	GSL	0.250

Note: Values in bold are statistically significant at p<0.05 level

Tab. 14. Pearson correlation coefficient between seasonal AMO and extreme temperature and precipitation indices in the 1961–2016 periods

Variable	Winter	Spring	Summer	Autumn
Tmax	0.033	0.079	**0.525**	0.214
TXx	0.146	0.201	**0.485**	0.164
TXn	-0.065	-0.179	0.078	0.117
TNx	0.223	-0.164	**0.452**	**0.391**
TNn	-0.044	-0.190	**0.285**	**0.266**
Variable	Winter	Spring	Summer	Autumn
Tmin	0.037	0.048	**0.588**	**0.378**
TX10p	0.153	-0.012	**-0.297**	-0.090
TX90p	0.109	0.062	**0.549**	**0.365**
TN10p	0.073	0.047	**-0.378**	**-0.317**
TN90p	0.114	0.149	**0.636**	**0.330**

Note: Values in bold are statistically significant at p<0.05 level

Conclusion

Based on daily maximum and minimum temperatures and daily precipitation during the 1961–2016 periods, trends in 27 extreme climate indices in Sarajevo (Bosnia and Herzegovina) were calculated in the RClimDex (1.0) software. The estimated trends in extreme temperature indices – the positive trends in warm temperature indices and the downward trends in cold ones – indicate presence of a warming tendency. The highest trend values were estimated for maximum values of daily maximum and minimum temperatures – TXx and TNx (0.76 °C and 0.53 °C per decade, respectively) and for warm temperature indices TX90p (9.66 days per decade), TN90p (8.20 days per decade), WSDI (6.39 days per decade), SU25 (6.25 days per decade) and SU30 (5.91 days per decade).

Thus, it can be concluded that warming tendency was greater in summer than in the colder part of a year. It should be noted that the observed trends have become more prominent since the beginning of the 21st century. Studies carried out at the global scale suggest that anthropogenic forcings (detectable and clearly separable from the natural signals) have influenced all temperature indices in recent decades and led to more prominent changes in the extremes frequency (Christidis & Stott, 2016; Easterling et al., 2016; Kim et al., 2016).

In contrary to the coherent warming trend, the extreme precipitation indices displayed trends mixed in sign (annually and seasonally), but all statistically insignificant. However, the upward trends in RX1day (0.68 mm per decade), RX5day (1.47 mm per decade), SDII (0.07 mm/days per decade), R99p (4.92 mm per decade), R10mm (0.23 days per decade) and R20mm (0.17 days per decade) suggest an increase in the magnitude and/or frequency of intense precipitation events.

The observed trends in extreme temperature indices are related with large-scale atmospheric circulation patterns over the Northern Hemisphere (primarily with the East-Atlantic pattern) and the Atlantic Multidecadal Oscillation. The negative correlation with the NAO, EAWR and AO was found for majority of extreme precipitation indices.

The results obtained in this survey are in concordance with the results of other studies related to changes in extreme climate (temperature and precipitation) indices previously carried out globally, continentally and regionally.

The future researches should be focused on several major issues regarding the observed trends in extreme climate indices: detecting and attributing observed changes in temperature and precipitation extremes; projecting future changes in extreme climate indices; and investigating the possible impact of the observed changes in extreme climate events (but also of the anticipated by the end of the 21st century) on socio-economic and natural systems (agriculture, forestry, energetics, tourism, biodiversity and ecosystem conservation, human health etc.).

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ПРОМЕНЕ ЕКСТРЕМНИХ КЛИМАТСКИХ ИНДЕКСА У САРАЈЕВУ (БОСНА И ХЕРЦЕГОВИНА)

Резиме: Студија анализира трендове екстремних климатских индекса у Сарајеву (Босна и Херцеговина). На основу максималних и минималних дневних температура и дневних падавина током периода 1961–2016, сет од 27 индекса које је препоручио CCl/CLIVAR тим експерата за детекцију савремених климатских промена (ETCCDI) израчунат је употребом софтвера RClimDex (1.0). С обзиром на резултате, индекси екстремних температура показали су тенденцију загревања током целе године (најистакнутији у лето). Позитивни трендови индекса топлих температура били су јачи од негативних трендова у хладним. Највеће вредности тренда процењене су за TXx, TNx, TX90p, TN90p, WSDI, SU25 и SU30. Индекси екстремних падавина показују трендове оба знака (годишњи и сезонски), али су сви статистички инсигнификантни. Међутим, растући трендови у R99p, RX1day, RX5day, SDII, R10mm и R20mm указују на повећање јачине и учесталости интензивних падавина. Такође, утврђене су значајне промене у дистрибуцији већине температурних индекса, док су промене индекса падавина углавном инсигнификантне. Уочене промене у индексима екстремних температура повезане су са обрасцима глобалне циркулације атмосфере (првенствено са Источно-атлантском осцилацијом) и Атлантском мултидекадном осцилацијом. Негативна корелација са Северноатлантском осцилацијом, Источноатлантском/Западно-руском и Арктичком осцилацијом утврђена је за већину индекса екстремних падавина.