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CHANGES IN TEMPERATURE EXTREMES IN BOSNIA AND HERZEGOVINA: A FIXED THRESHOLDS-BASED INDEX ANALYSIS

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Abstract: The paper analyzes trends in the extreme temperature indices based on fixed thresholds in Bosnia and Herzegovina during the 1961–2016. Based on data from 12 meteorological stations, trends in both warm and cold temperature indices were determined using the nonparametric Mann-Kendall test and the nonparametric Sen's slope estimator. The observed tendencies in indices based on fixed thresholds were as expected in a warming world – warm temperature indices (summer days, tropical days and tropical nights) displayed the significant positive trends, whereas cold temperature indices (icing days and frost days) showed the downward tendencies. The annual occurrence of summer days and tropical days increased on average for 5.3 and 4.8 days per decade, respectively, whereas icing days and frost days displayed downward trends in the range of -1.7 and -3.6 days per decade, respectively. The obtained results indicate that the climate system warming was more a result of very pronounced positive trends in the warm temperature indices than the downward tendency of cold ones. The most prominent changes were observed in Banja Luka, Bugojno and Zenica regions. Both trends, positive in warm indices and negative in cold ones, become more pronounced in the 1990s and particularly since the beginning of the 21st century. Further research should focus on the assessment of the observed trends impacts on natural and socio-economic systems.

Keywords: temperature, indices based on fixed thresholds, trend, climate change, Bosnia and Herzegovina

Introduction

A large majority of global land areas had displayed unequivocal warming of the climate system in the second half of the 20th century (Hartmann et al., 2013). Both mean temperatures as well as the frequency, intensity, and duration of temperature extremes had experienced significant patterns of change (IPCC, 2014). Global scale studies on extreme temperature indices showed that these changes in all extreme temperature-related indices were generally as expected in a warming world: warm temperature extremes displayed the upward trends, whereas cold ones showed the downward trends (Alexander et al., 2006). The

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global scale changes in the indices based on fixed thresholds (which are the main research issue of this study) also displayed trends consistent with the global climate system warming. The annual occurrence of cold temperature indices (e.g. frost days) decreased over the second half of the 20th century. Conversely, the annual occurrence of warm temperature indices (e.g. summer days and tropical nights) showed significant upward trends in a majority of world regions (Frich et al., 2002; Alexander et al., 2006). These globally observed patterns of change in temperature indices based on fixed thresholds were confirmed by numerous continental, regional and local studies all over the world: in North and South America (Brown Bradley & Keimig, 2010; Skansi et al., 2013), Asia (Zhou & Ren, 2011; Sheikh et al., 2015), Africa (Filahi, Tanarhte, Mouhir, El Morhit, & Tramblay, 2016), Australia and New Zealand (Caloiero, 2017).

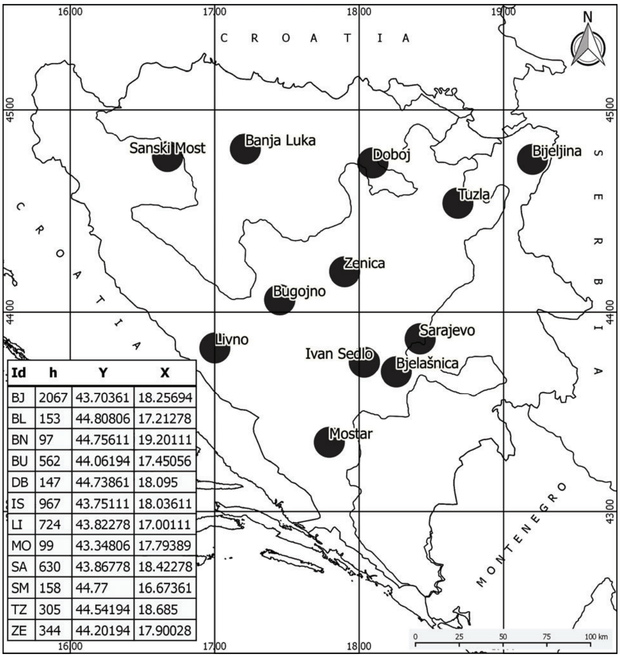
Higher frequency and greater magnitude of warm extremes and rarer occurrence of cold ones during the second half of the 20th century and at the beginning of the 21st century were also determined for Europe at the continental scale (Klein Tank, & Können, 2003) and in its various regions, including the Iberian Peninsula (Fonseca, Carvalho, Marta-Almeida, Melo-Gonçalves, & Rocha, 2016), Apennine Peninsula (Fioravanti, Piervitali, & Desiato, 2016), Carpathian Basin (Bartholy & Pongrácz, 2007; Lakatos, Bihari, Szentimrey, Spinoni, & Szalai, 2016), Central Europe (Nemec, Gruber, Chimani, & Auer, 2013), Scandinavia (Kivinen, Rasmus, Jylhä, & Laapas, 2017), including the Southeast Europe region where Bosnia and Herzegovina is located (Kioutsioukis, Melas, & Zerefos, 2010; Branković et al., 2013; Burić, Luković, Ducić, Dragojlović, & Doderović, 2014; Knežević, Tošić, Unkašević, & Pejanović, 2014; Ruml et al., 2017). In Croatia, the upward trend in the annual number of summer days was in the range of 2–8 days per decade, whereas decrease in the number of frost days was mostly up to 2 days per decade (Branković et al., 2013). The dominant trend in frost days in Serbia was negative for the winter and spring seasons, whereas tropical nights displayed the positive one (Knežević et al., 2014). The annual number of summer days in Italy was above the 1961–1990 averages over the last 30 years (except in a few years), as well as the annual occurrence of tropical nights (Fioravanti et al., 2016). The significant positive trends at 65% of stations in Greece resulted in a substantial increase of the upper bound of tropical night's distribution (Kioutsioukis et al., 2010). In southern part of Montenegro, frequency of frost days declined -0.5 days per decade, whereas annual numbers of summer days and tropical nights increased 2.9 and 5.4 days per decade, respectively. The annual occurrence of icing days and frost days over the Carpathian region displayed downward tendency in the range of -1.8 and -2.5 days per decade, respectively, whereas the increase in the annual number of summer days was even more prominent (3.7 days per decade) (Lakatos et al., 2016).

Previous studies on mean temperatures determined that the climate system warming had been present over the territory of Bosnia and Herzegovina throughout the year (most prominent in summer season) (Trbić, Popov, & Gnjato, 2017). However, a comprehensive research on trends in the extreme temperature indices based on fixed thresholds has not been carried out so far for this area, although a few studies (Popov, Gnjato, & Trbić, 2017a; 2017b) have partially addressed this issue. The main goal of this study is to analyze trends in both warm and cold indices based on fixed thresholds over Bosnia and Herzegovina using five internationally agreed extreme temperature indices for the recent climate change assessment.

Data and methods

The analysis of trends in extreme temperature indices based on fixed thresholds during the 1961–2016 was carried out using data from 12 meteorological stations located in all three macroregions of Bosnia and Herzegovina — (1) Peripannonian, which covers lowland area of the Pannonian Plain and its southern rim in northern part of the country (SM, BL, DB, TZ, BN and ZN station); (2) Dinaric mountain range, which covers the largest part of the territory (SA, BJ and BU station) and (3) Submediterranean, which includes the Herzegovina region in the south that is subjected to the Mediterranean (Adriatic) influences (IS, LI and MO station) (Figure 1). Due to its geographical position, climate varies from moderate continental in the northern part of the territory (continental in the extreme northeast), mountain climate on high mountains in the central part of the territory to modified Submediterranean climate in the south. Given the geographical configuration, the selected stations covered a wide range of altitudes — from 97 m at Bijeljina station to 2 067 m above sea level at Bjelašnica station.

Data on monthly time series of the temperature indices based on fixed thresholds were provided by the Republic Hydrometeorological Service of the Republic of Srpska and the Federal Hydrometeorological Institute. Given that there were some interruptions in measurements in the war and post-war periods (1992−1997, only at Bjelašnica station until 1999) at the majority of stations, missing data extrapolation was carried out using data from the nearest station with available measurements in the corresponding period.



Id	h	Y	X
BJ	2067	43.70361	18.25694
BL	153	44.80806	17.21278
BN	97	44.75611	19.20111
BU	562	44.06194	17.45056
DB	147	44.73861	18.095
IS	967	43.75111	18.03611
LI	724	43.82278	17.00111
MO	99	43.34806	17.79389
SA	630	43.86778	18.42278
SM	158	44.77	16.67361
TZ	305	44.54194	18.685
ZE	344	44.20194	17.90028

Figure 1. Geographical locations of the meteorological stations used in the study

The recent variability in extreme temperatures over Bosnia and Herzegovina was determined by trends in the 5 indices based on fixed thresholds that were selected from the list of a 27 internationally agreed temperature and precipitation extreme indices defined by the joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) (Retrieved from: http://etccdi.pacificclimate.org/list_27_indices.shtml,) which are used worldwide for climate change assessment. These indices are defined as the annual number of days on which a temperature value falls above or below a fixed threshold:

- Number of icing days (ID0): annual count of days when daily maximum temperature < 0 °C
- Number of frost days (FD0): annual count of days when daily minimum temperature < 0 °C
- Number of summer days (SU25): annual count of days when daily maximum temperature > 25 °C
- Number of tropical days (TR30): annual count of days when daily maximum temperature > 30 °C
- Number of tropical nights (TR20): annual count of days when daily minimum temperature > 20 °C.

Trends in the selected temperature indices based on fixed thresholds were analyzed by stations individually and then the averaged trend values for the whole territory of Bosnia and Herzegovina were estimated. Data series of threshold-based indices were subjected to the nonparametric Mann-Kendall test in order to determine the possible existence of a trend in the time series and its statistical significance. The statistical significance of the estimated trend values was defined at the 99.9%, 99%, 95% and 90% levels. The Sen's nonparametric estimator of slope determined the trend magnitude (change per unit time). The percentile analysis was performed to further examine changes in selected indices. The nonparametric Kolmogorov-Smirnov test was used to investigate changes in cumulative distributions of temperature indices between two thirty-year periods – the standard climatological period (1961–1990) and the period of the last thirty years (1987–2016), whereas the t-test determined the statistical significance of the differences in the indices annual values the two specified periods. All calculations were made in XLSTAT Version 2014.5.03.

Results and discussion

An overview of the average annual values of the indices used in the study during the 1961–2016 in Bosnia and Herzegovina is given in the Table 1. The Figure 2 displays its monthly frequencies of occurrence. In the northern part of Bosnia and Herzegovina, 16–19 icing days (ID0) occur annually on average, during the November–March periods, but with the highest frequency in winter. The number of icing days increases towards the high mountainous areas in the central part of Bosnia and Herzegovina (e.g. 125 such days occur at Bjelašnica station annually). In higher parts of the Herzegovina region, icing days occur during the November–March periods, whereas in the lower areas of this region this occurrence is very rare (only one such day on average is recorded annually). Over the Peripannonian region, the annual frequency of occurrence of frost days (FD0) is 23–26%. They occur during the October–April periods, with the highest frequency during the two coldest months — January and December. The average annual number of frost days was also the highest over the high mountainous area of the Dinaric region. The maximum frequency is recorded at the two highest located analyzed stations – Bjelašnica and Ivan Sedlo. At Bjelašnica station frost days occur throughout the year (the annual frequency of occurrence is 52%), but the highest frequencies are recorded during the November–April periods. The occurrence of frost days is also very frequent in the higher areas of Herzegovina region (the annual frequency of occurrence is about 30%). The lowest frequency of frost days has been characteristic of lower areas in this region, where only 20 such days occur annually.

Table 1. Average annual frequency of temperature indices based on fixed thresholds in Bosnia and Herzegovina in 1961–2016

days	SM	BL	DB	TZ	BN	BU	ZN	SA	BJ	IS	LI	MO	B&H
ID0	16	17	16	19	17	22	16	23	125	40	11	1	27
FD0	94	85	82	90	85	109	88	89	189	112	110	20	96
SU25	92	95	94	88	104	75	98	75	0	31	66	129	79
TR30	30	34	31	27	40	23	37	22	0	5	18	68	28
TR20	0	1	1	0	2	0	0	1	0	0	0	30	3
%	SM	BL	DB	TZ	BN	BU	ZN	SA	BJ	IS	LI	MO	B&H
ID0	4	5	4	5	5	6	4	6	34	11	3	0	7
FD0	26	23	23	25	23	30	24	23	52	31	30	5	26
SU25	25	26	26	24	29	20	27	20	0	8	18	35	22
TR30	8	9	8	7	11	6	10	6	0	1	5	19	8
TR20	0	0	0	0	0	0	0	0	0	0	0	8	1

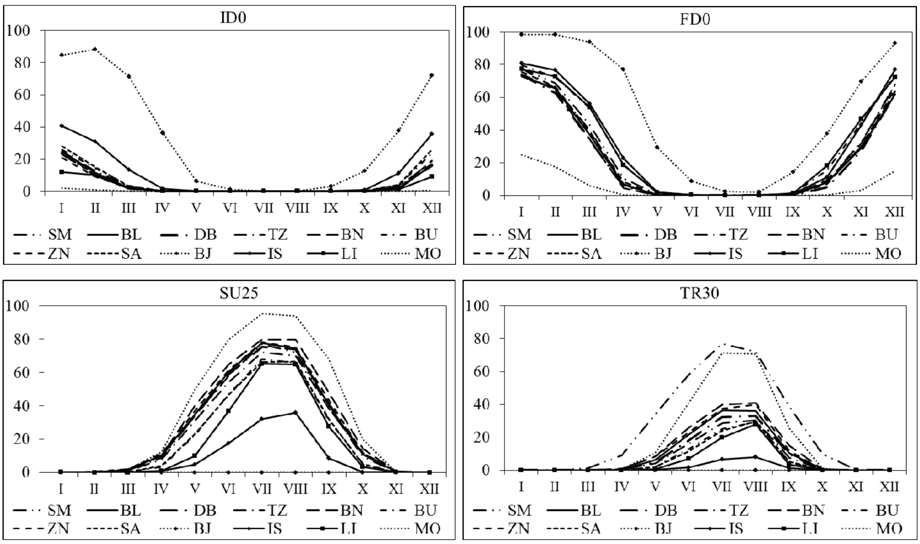


Figure 2. Temperature indices monthly frequency (%) in Bosnia and Herzegovina in 1961–2016

Warm temperature indices, summer days (SU25) and tropical days (TR30), over the lower areas in the northern and central parts of Bosnia and Herzegovina occur during the April–October and May–September periods, respectively. Most frequent are in summer season — particularly in July and August (frequency of occurrence being 66–80% and 24–41%, respectively). Their annual frequency is in the range of 20–29% and 6–11%, respectively. The highest annual numbers of these warm temperature indices are recorded in the south (e.g. in Mostar) and in the extreme northeast (e.g. in Bijeljina). Summer days and tropical days do not occur in high mountainous areas (e.g. Bjelašnica). The occurrence of tropical nights (TR20) is very rare over the vast majority of areas in Bosnia and Herzegovina. Only 1 or 2 such days have usually been recorded annually (solely in summer season). In the higher mountain areas, their occurrence has never been recorded. TR20 frequently occur only in the southern lower areas (e.g. in Mostar area), mainly during the June–September periods, although their frequency of occurrence is the highest during the two hottest months — July and August (about 40%). Considering the stated, trend analysis of the tropical nights occurrence was carried out only for this area.

The observed trends in temperature indices based on fixed thresholds in Bosnia and Herzegovina were also as expected in the warmed world. Cold temperature indices ID0 and FD0 showed downward tendencies, whereas warm temperature indices SU25, TR30 and TR20 displayed even more prominent positive trends (Table 2). During the observed 1961–2016 periods, ID0 displayed downward trends in the range of -1.7 (-0.8 – -2.7) days per decade over almost the entire territory of Bosnia and Herzegovina (except at the highest mountainous areas where no trend was present, e.g. Bjelašnica). The estimated trend values were relatively low, but statistically significant at all stations, except in the extreme northeast (Bijeljina). The negative trend in FD0, also present over the entire territory, was even more prominent and significant. The estimated trend values were in the range of -3.6 (-2.2 – -6.3) days per decade. Although no trend was found in the ID0 at the highest located station of Bjelašnica, the decreasing trend in FD0 was very strong (-4.1 days per decade). The downward trends in cold temperature indices ID0 and FD0 were most pronounced in the area of Banja Luka (-2.4 and -6.3 days per decade), Bugojno (-2.5 and -5.1 days per decade) and Zenica (-2.7 and -4.4 days per decade) (Figure 3).

Table 2. Decadal trends in temperature indices based on fixed thresholds in Bosnia and Herzegovina in 1961–2016 (days per decade)

Station	SM	BL	DB	TZ	BN	BU	ZN	SA	BJ	IS	LI	MO	B&H
ID0	-1.8[c]	-2.4[a]	-1.8[c]	-2.2[b]	-0.8	-2.5[a]	-2.7[a]	-2.3[b]	0.0	-2.2[c]	-1.5[c]		-1.7[b]
FD0	-3.3[b]	-6.3[a]	-2.4[c]	-3.0[c]	-3.1[d]	-5.1[a]	-4.4[a]	-3.0[c]	-4.1[a]	-3.3[b]	-3.0[c]	-2.2[b]	-3.6[a]
SU25	5.3[a]	7.4[a]	4.2[b]	5.6[a]	3.8[b]	6.1[a]	8.2[a]	6.0[a]		6.5[a]	7.2[a]	3.0[c]	5.3[a]
TR30	4.3[a]	6.2[a]	4.2[b]	4.8[a]	5.2[a]	5.2[a]	8.1[a]	5.9[a]		1.2[a]	6.1[a]	4.4[a]	4.8[a]
TR20												6.3[a]	

Note: Statistical significance at the 99.9% ([a]), 99% ([b]), 95% ([c]) and 90% ([d]) levels

Warm temperature indices SU25 and TR30 displayed statistically significant positive trends over the entire territory of Bosnia and Herzegovina. The increase in annual SU25 and TR30 was in the range of 5.3 (3.0–8.2) days per decade and 4.8 (1.2–8.1) days per decade, respectively. The SU25 trend was most prominent in Zenica (8.2 days per decade), Banja Luka (7.4 days per decade) and in the higher parts of Herzegovina region — Livno (7.2 days per decade) and Ivan

Sedlo (6.5 days per decade) (Figure 3). Zenica, Banja Luka and Livno areas also displayed the most pronounced trends in TR30 (8.1, 6.2 and 6.1 days per decade, respectively). Although the TR30 trend value at Ivan Sedlo (967 m) was relatively low, it is statistically significant (at the 99.9% level), because over this area during the standard climatological period only 2 such days occurred annually on average, while their frequency increased 4-fold over the last 30 years. The statistically significant upward trend in TR20 in the range of 6.3 days per decade was found in the Mostar area. In other parts of Bosnia and Herzegovina where the annual occurrence of tropical nights was very rare (none or only 1–2 such days have usually been recorded annually), although there was no trend in the time series, the noticeable increase in their frequency was determined during the last decades, and particularly since the beginning of the 21st century. Maximum frequencies of TR20 were recorded in years with the occurrence of long-lasting and intense heat waves – particularly in 2007, 2010 and 2012. The effect of the urban heat island contributed to greater warming rates in major cities. For instance, in Banja Luka only 8 TR20 occurred during the standard climatological period, whereas even 75 TR20 have been recorded after 1990 (maximum 10 and 7 TR20 in summer 2012 and 2010, respectively). In Zenica, only one TR20 occurred in 30 years, but 16 such days have been observed after 1990. During the heat wave in summer 2007, the occurrence of 8 TR20 was recorded in Sarajevo. In the same period, 3 TR20 occurred in Livno area, where only one such day had been recorded in the 1961–1990 period. Even in the areas where during the standard climatological period a total of 1 or 2 TR20 were recorded, their occurrence has become more frequent in the 21st century (e.g. at Sanski Most, Bugojno and Ivan Sedlo areas).

It should be noted that the positive trends in warm temperature indices SU25, TR30 and TR20 were much more prominent than the negative trends estimated for cold indices ID0 and FD0. It can be concluded that the observed increasing warming tendency was more the result of rising frequency warm indices extremes than the reduction in frequency of cold ones. The stated is in accordance with the results of the previous studies carried out in Bosnia and Herzegovina which determined that the warming trend was the strongest in the summer season (Popov et al., 2017a; Trbic et al., 2017) and follows the results of the other studies carried out in the Southeast Europe region (Branković et al., 2013; Burić et al., 2014; Knežević et al., 2014). Similar trends in the temperature indices based on fixed thresholds were found globally (Alexander et al., 2006) and in Europe at the continental scale (Klein Tank & Können, 2003). For instance, the continentally averaged annual number of frost days declined -1.7 days per decade, whereas annual occurrence of summer days increased 0.8 days per decade (Klein Tank & Können, 2003).

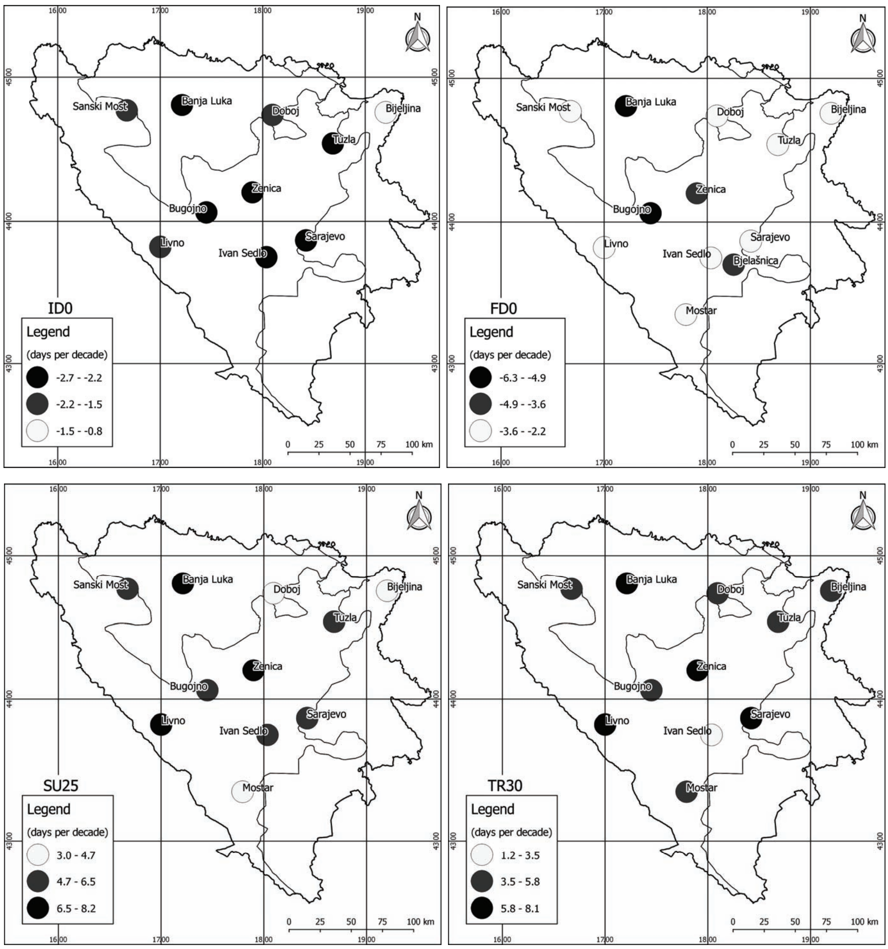


Figure 3. Decadal trends in temperature indices in Bosnia and Herzegovina in 1961–2016

Both of the observed tendencies (increase in warm indices frequency and decline in cold ones) become more pronounced after 1990 and particularly since the beginning of the 21st century. The results given in the Table 3 show that among years with highest/lowest values of warm/cold temperature indices, there were only a few years prior to 1990 (the vast majority of them was recorded in the 21st century, particularly for the warm indices SU25, TR30 and TR20). The extremely low frequencies of cold temperature indices ID0 and FD0 were recorded in 2014, which was the hottest year in the observed period over the vast majority of areas. On the other hand, the maximum values of warm indices SU25, TR30 and TR20 were recorded in 2012 and 2003, years with the occurrence of the long-lasting and intense heat waves in summer season. For instance, in 2014 in Banja Luka there were only 4 ID0 (77% less than the average) and 34 FD0 (60% less than the average), whereas in 2012 and 2003 even 135 SU25 (41% more than the average) and 79 and 68 TR30 (131% and 99% more than the average, respectively) were recorded.

Table 3. Top 5 years with the highest/lowest values of warm/cold indices in the 1961–2016 periods

No.	ID0B&H		FD0B&H		SU25B&H		TR30B&H		TR20MO	
	Value	Year	Value	Year	Value	Year	Value	Year	Value	Year
1.	14	2014	51	2014	113	2012	67	2012	69	2012
2.	16	2015	72	2008	110	2003	58	2003	66	2003
3.	17	2013	76	2007	103	2011	53	2015	62	2015
4.	17	1974	77	2009	101	2009	49	2000	55	2008
5.	17	1989	79	1994	101	2000	48	2007	52	1994

The indices deviations from the standard climatological periods averages (calculated as a difference from the 1961–1990 averages) illustrated in the Figure 4 also confirm stronger warming tendency since the beginning of the 21st century.

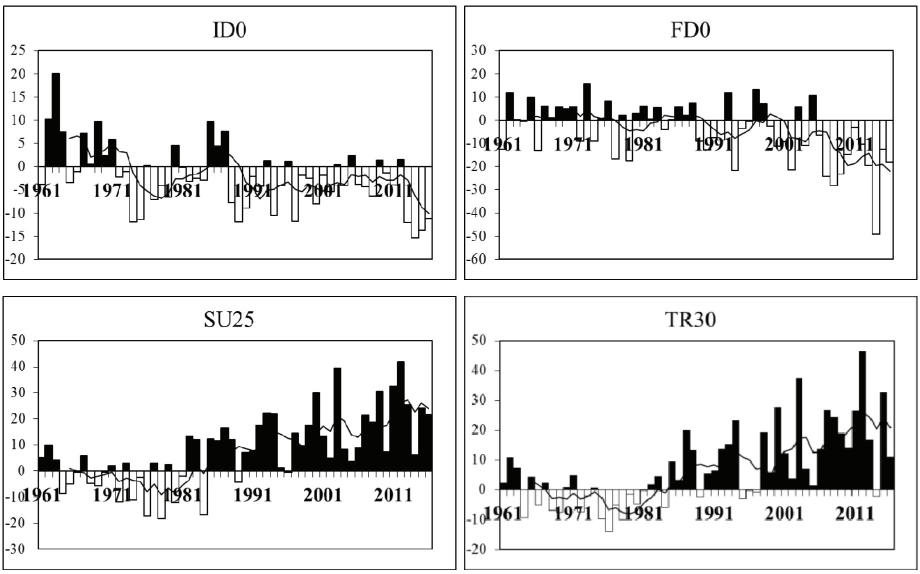


Figure 4. Annual deviations of the temperature indices from the standard climatological period (1961–1990) averages (the bold line represents the 5-year moving averages)

The averaged values of SU25 displayed not a single occurrence below the standard climatological period averages. Only a few stations recorded one or two years below the average (mainly in 2005). The TR30 displayed the below averaged values only in 2014, during which period, although it was the hottest year, no extremely high temperatures and heat waves occurrence were recorded. Lower than average frequencies were also observed in Doboj, Zenica and Sanski Most in 2005 and Mostar in 2002. TR20 has been displaying positive deviations in Mostar since 1987 (with the exception of 2014). Since the beginning of the 21st century, cold temperature indices were mostly below average, thus confirming the increasing warming tendency. The above average occurrences were determined mainly in 2005 and 2009 (in the case of ID0 in 2012) due to extremely cold winters in these years. The percentile analysis also confirms a rapid decline in the occurrence of cold temperature indices ID0 and FD0 and even more pronounced increase in warm temperature indices SU25, TR30 and TR20 since the 1990 and particularly during the last decade (Figure 5).

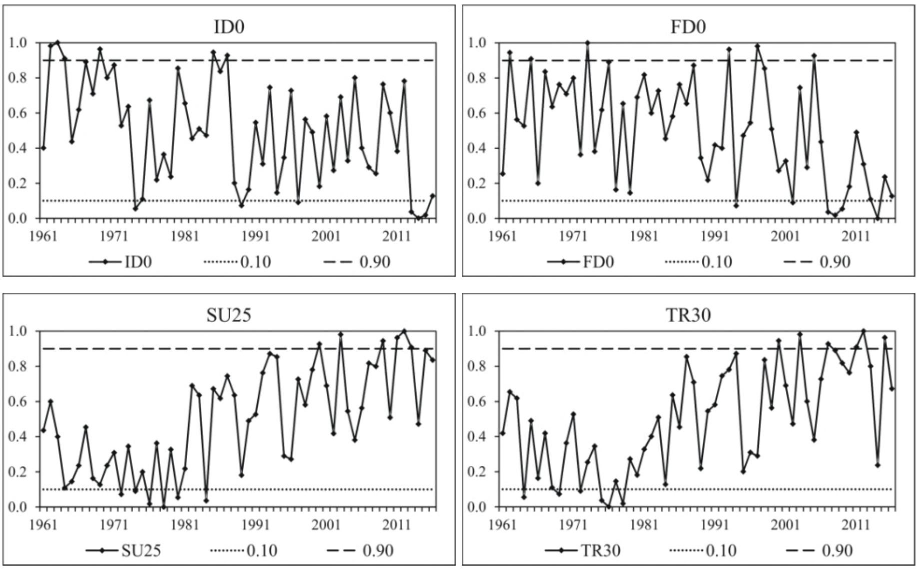


Figure 5. Temperature indices percentile ranks in Bosnia and Herzegovina in 1961–2016

ID0 analysis showed that after 1990, every third or fourth year on average was below the 25th percentile at all stations. Majority of stations registered even 3–4 years below the 10th percentile (all in the 21st century – mainly in the 2013–2015 period). Since the beginning of the 21st century, only broader Sarajevo area (Sarajevo, Bjelašnica and Ivan Sedlo) registered one year above the 90th percentile (2005). In Tuzla and Bijeljina area, 1996 was above the 90th percentile. After 1990, FD0 frequency of occurrence displayed every third year on average below the 25th percentile, whereas every fifth year on average was even below the 10th percentile. On the other hand, only 1–3 years were above the 90th percentile. Banja Luka and Bjelašnica registered not a single occurrence above the 90th percentile since the 1990, whereas Sanski Most, Bugojno and Zenica displayed not a single occurrence in the 21st century. Warm temperature indices SU25 and TR30 after 1990 registered every second or third year above the 75th percentile (4–6 years even above the 90th percentile, all after 2000 except 1994 at some stations). In contrast, they displayed not a single occurrence below the 10th percentile. Only at two station SU25 registered one year in this category during the 1990s. Similar was determined for TR30. The significant increasing frequency of TR20 occurrence in Mostar (Figure 6) indicates the fact that the last year with the frequency below the 10th percentile was 1984. Moreover, after that year, only one year was below the 25th percentile (2014). In contrast, every other year after 1990 was above the 75th percentile (12 out of 13 years in this category were recorded in the 21st century).

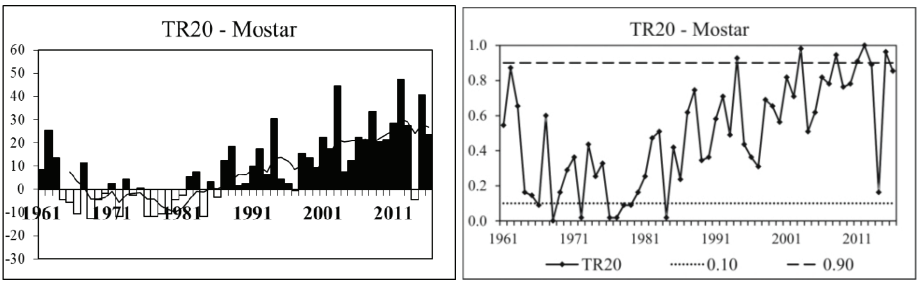


Figure 6. TR20 deviations (left) and percentile ranks (right) in Mostar in 1961–2016

Changes in cumulative distributions of the analyzed indices between the 1987–2016 period and the 1961–1990 period are displayed in the Figure 7. The Kolmogorov-Smirnov test results showed that the indices distributions were statistically different in the latter period compared to the standard climatological period. Consistent with the warming trend, the mean values of the warm temperature indices SU25, TR30 and TR20 distributions between two specified periods shifted to the right towards higher values. Corresponding shifts to the left towards lower occurrence frequencies of the cold temperature indices FD0 and ID0 distributions were also determined (however, somewhat less significant).

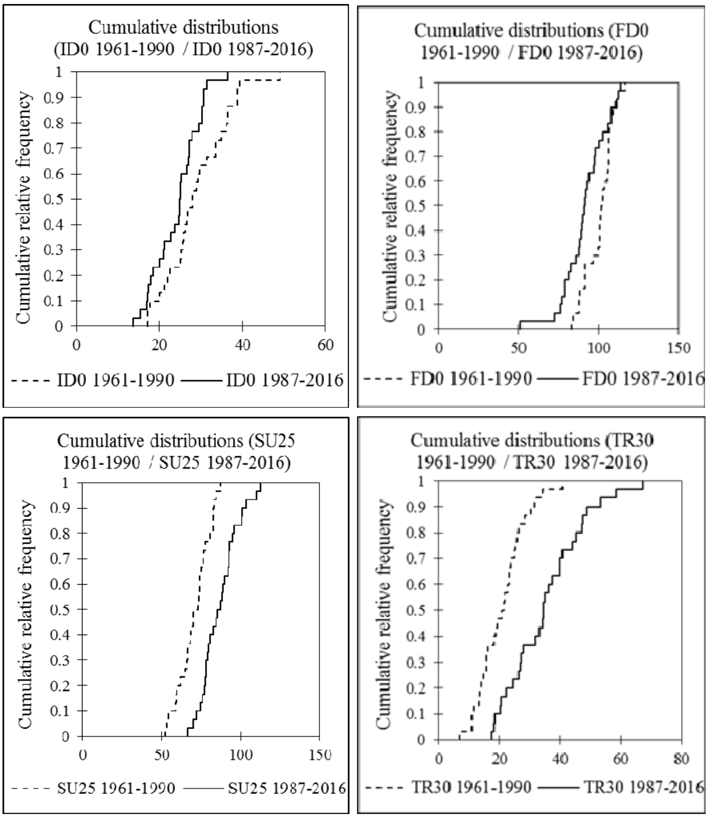


Figure 7. Changes in cumulative distributions of temperature indices in 1987–2016 relative to 1961–1990

Table 4. Average annual values of temperature indices in Bosnia and Herzegovina in 1961–1990 (a) and 1987–2016 (b) and difference between averages in 1987–2016 relative to 1961–1990 (c)

Index		SM	BL	DB	TZ	BN	BU	ZN	SA	BJ	IS	LI	MO	B&H
ID0	a	19	20	18	21	18	25	20	26	126	43	12	1	29
	b	13	14	14	16	16	18	12	20	124	37	9	1	24
	c	-6[c]	-6[c]	-5[c]	-5[c]	-2	-7[b]	-8[a]	-6[b]	-3	-6[c]	-4[d]	-1	-5[b]
FD0	a	97	95	84	94	87	117	94	93	195	116	114	22	101
	b	90	76	81	88	84	101	81	85	183	107	105	18	92
	c	-8[d]	-19[a]	-3	-6[d]	-3	-15[a]	-13[a]	-7[d]	-12[a]	-9[c]	-9[b]	-4[d]	-9[b]
SU25	a	84	85	87	79	98	65	87	65	0	21	55	124	71
	b	100	106	100	96	111	84	111	83	0	42	76	134	87
	c	16[a]	21[a]	13[b]	17[a]	13[a]	19[a]	24[a]	18[a]	0	21[a]	22[a]	10[b]	16[a]
TR30	a	23	25	24	19	32	15	26	14	0	2	9	60	21
	b	37	43	36	35	49	31	50	31	0	9	26	75	35
	c	14[a]	18[a]	12[b]	16[a]	17[a]	16[a]	24[a]	17[a]	0	7[b]	17[a]	15[a]	15[a]

Note: Statistical significance at the 99.9% ([a]), 99% ([b]), 95% ([c]) and 90% ([d]) levels

The Table 4 shows that average annual SU25 and TR30 significantly increased in the latter period (by 10–24 days for SU25 and 7–24 days for TR30), whereas the frequencies of ID0 and FD0 significantly decreased over almost entire territory of Bosnia and Herzegovina — insignificant decline was registered only in Bijeljina and Bjelašnica for ID0 and Bijeljina and Doboj for FD0.

Conclusion

This study addresses the issue of changes in the frequency of extreme temperature indices based on fixed thresholds (recommended by the ETCCDI) in Bosnia and Herzegovina during the 1961–2016. The trend analysis determined that there has been a significant increase in the frequency of warm extremes, whereas cold extremes have displayed a downward tendency. However, both trends suggest warming of the climate over the Bosnia and Herzegovina territory. The higher trend values estimated for SU25 (5.3 days per decade), TR30 (4.8 days per decade) and TR20 (in Mostar 6.3 days per decade) than for cold indices FD0 (-3.6 days per decade) and particularly ID0 (-1.7 days per decade) indicate that climate system warming is more a consequence of a high and rapid increase in warm extremes. The most prominent changes in both warm and cold indices were observed in Banja Luka, Bugojno and Zenica area. All indices displayed stronger trends in last decade of the 20th century and particularly since the beginning of the 21st century. The results obtained in this survey follow the results of the previous studies in this part of Europe, but also the results of the global and continental scale studies. The future research should be focused on projections of future changes in temperature extremes. Given that the observed changes in extreme temperature indices based on fixed thresholds will have diverse impacts on key sectors in Bosnia and Herzegovina, the results of this study can have various applications in different socio-economic sectors – agriculture, forestry, hydropower, tourism, public health, but also in hazard risk assessment and environment conservation.

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