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RECENT AND FUTURE AIR TEMPERATURE AND PRECIPITATION CHANGES IN THE MOUNTAINOUS NORTH OF MONTENEGRO

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Abstract: The aim of the research of this paper is changes in air temperature and precipitation in the north of Montenegro in the instrumental period (1951–2018) and projections up to 2100. Kolašin was chosen because the altitude of the place is the average height of the northern region of Montenegro (about 1000 m), the meteorological station has not changed its location since the beginning of instrumental measurements, and homogeneity was tested (for the instrumental period). In general, the climate of Kolašin (1951–2018) has become warmer and with more frequent extreme daily temperatures and precipitations in an upward trend. When it comes to the projections for the north of this Mediterranean country, according to the A1B scenario of the Regional Climate Model EBU-POM, the results indicate warmer conditions and very warm ones at the end of the 21st century. The projected reduction of the annual number of almost all the considered rainfall days also implies that a slightly more arid future is expected. The climate of the mountainous north of Montenegro is changing, and the results presented in this paper may serve decision makers to take some measures of adaptation (in tourism, agriculture, architecture, water management, etc.) and climate change mitigation.

Keywords: Montenegro; Kolašin; temperature and precipitation indices; climate changes

Introduction

Montenegro is a part of the Western Balkans, i.e., Southeastern Europe and the Mediterranean. Studies say that the Mediterranean region (Intergovernmental Panel on Climate Change [IPCC], 2014; Mostafa et al., 2019) is among the most vulnerable to climate changes in the world. In the period 1961–2006, most of Spain (Del Río, Cano-Ortiz, Herrero, & Penas, 2012) recorded a trend of increasing maximum and minimum temperatures. From 1976 to 2013 in Haifa (Israel) there was a trend of a longer dry period of 1 day per year (Wittenberg & Kutiel, 2016).

Accordingly, in Southeastern Europe, as well as in much of the Mediterranean, the proportion of weather extremes has increased over the past five to six decades, with projections indicating that these regions will become warmer and drier in the future (IPCC, 2014). According to climate projections (Djurdjevic, Trbić, Krzic, & Bozanic, 2019; Giorgi, 2006), the Western Balkans may face significant climate changes in the future, especially as it is a region that is highly vulnerable

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*Corresponding author, e-mail: dragan.buric@meteo.co.me compared to much of the European continent. The results for neighboring Serbia show that in the second half of the 20th and at the beginning of the 21st century, a trend of increasing maximum and minimum temperatures was recorded (Unkašević & Tošić, 2013), and that the period 2071–2100 will be warmer by about 2 °C and 4 °C for the A1B and A2 scenarios, respectively (Kržić, Tošić, Djurdjević, Veljković, & Rajković, 2011).

Montenegro is a spatially small Mediterranean country, with a total area of 13,812 km^2. The Northern region covers about 50% of this country. The north of Montenegro is a mountainous area with numerous plains and river valleys. The region is rich in deciduous and coniferous forests. The main occupation of the population in this region is agriculture and forest exploitation. In recent years, rural tourism and organic agriculture have been developing and mini hydroelectric power plants have been built on mountain rivers. These activities are highly dependent on climatic conditions, so this paper seeks to answer the following research questions:

- What is the extent of changes in temperature and precipitation in the north of Montenegro (Kolašin)?
- What will the future be like according to the projections of the temperate (most probable) scenario (A1B) of the Regional Climate Model (RCM) EBU-POM?

The results obtained may make the decision-makers in this country become aware of what happens with the climate and what the future holds for us in the example of city Kolašin, in order to consider taking certain measures in the economy, especially in the primary branches of the economy in Montenegro, namely tourism, agriculture, and water management.

Materials and methods

The study covers the area of Kolašin which belongs to the northern region of Montenegro (Figure 1). The main factors that influence the formation of the climate of Kolašin are: its latitude, air currents, and altitude. The urban area is located at about 900–1,000 m a.s.l., whereas the weather station is at 944 m above sea level. The city area is surrounded by mountain ranges with peaks up to 2,400 m a.s.l., and the entire municipality of Kolašin has 8,300 inhabitants (according to the 2011 census). According to Köppen's climate classification, urban areas and lower terrain have the characteristics of moderate continental climate (climate formula *Csbx'*), while higher mountain areas of Kolašin (altitude above 1,000 m) have characteristics of *D* climate—moderately cold climate (Burić, Ducić, & Mihajlović, 2014).

For the purposes of the study, data from the main meteorological station in Kolašin, whose coordinates are 42°49'22''N, 19°31'4''E, and altitude of 944 m a.s.l. were used. Continuous measurements and observations of meteorological elements and weather phenomena in Kolašin began in 1949. Daily and monthly air temperature and precipitation data were obtained from the Institute for Hydrometeorology and Seismology of Montenegro (IHMS). For the analyzed period of 68 years (1951–2018) the percentage of missing data was negligible (1–3%), depending on the time series of temperature, i.e., precipitation. For the purposes of this study, the examination of the homogeneity of the time series of temperature and precipitation for the instrumental period was done using the MASH method, version MASHv3.02 (Szentimrey, 2007).

Using the results of the global climate model ECHAM5 (Roeckner et al., 2003) and the ocean model MPI-OM, Djurdjevic and Rajkovic (2011) developed a dynamically adapted RCM for the Mediterranean region of Europe: EBU-POM. The atmospheric part of the model is a version of Eta/NCEP model (Janjic, 1979; Janjic, Gerrity Jr, & Nickovic, 2001; Mesinger, 1974; Mesinger, Janjić, Ničković, Gavrilov, & Deaven, 1988) and the ocean part is the Princeton Ocean Model (POM) (Blumberg & Mellor, 1987). The Horizontal resolution of EBU-POM model is 25 km. For the purposes of this paper, the authors made projections for the Special Report on Emission Scenarios (Nakićenović et al., 2000) A1B scenario. Bias correction algorithms are based on observations, and the model data is modified based on the reference period 1961–1990. Simulations of the future climate for the A1B scenario were done for the period 2001–2100 (Djurdjevic & Rajkovic, 2011).

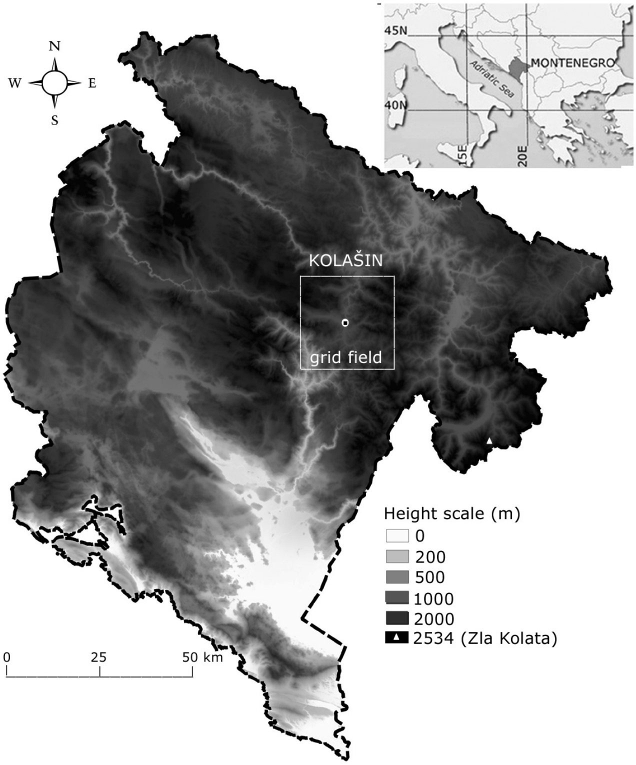

Figure 1. Position of Montenegro in Southeastern Europe and Kolašin in Montenegro.

The total of 18 temperature parameters (indices) and 14 precipitation ones were used. The definitions and abbreviations of the temperature parameters used in this study are given in Table 1. The indices numbered 1 to 7 refer to the mean, mean maximum and mean minimum annual, and seasonal temperatures (*TY*, *TW*, *TSp*, *TSu*, *TA*, *TYx*, *TYn*). The suffixes *x* and *n* indicate maximum and minimum temperatures (e.g., *TYx*, *TYn*). The indices were defined by the number of days exceeding fixed or percentile temperature thresholds (11 indices in total), taken from Peterson et al. (2001) and World Meteorological Organization (2009) and they are calculated according to the standards proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI), which is supported by the World Meteorological Organization (WMO) Commission on Climatology, the Joint Commission on Oceanography and Marine Meteorology (JCOMM) and the Research Program on Climate Variability and Predictability (CLIVAR) (WMO, 2004). Five temperature indices (*Tx10, Tn10, Tx90, Tn90,* and *WSDIN*) were defined using percentiles (10th and 90th percentiles of maximum (*Tx*) and minimum (*Tn*) daily air temperature values for the reference period (1961–1990). The other 6 parameters were defined based on the number of days with temperatures above or below the fixed thresholds (*FD, ID, SU, TD, TR,* and *GSL*). To describe precipitation conditions, 14 indices were used—five refer to annual and seasonal precipitation (*RY, RW, RSp, RSu,* and *RA*) and nine (taken from Peterson et al., 2001 and WMO, 2009) refer to the number of days above the fixed thresholds (*R0.1, R1, R10, R20, R30, R40, R50, CDD,* and *CWD*).

Table 1
Abbreviations, definitions and units of used temperature and precipitation parameters

No.	Parameter	Definition	Unit
		Temperature	
1.	*TY*	Mean annual temperature	°C
2.	*TW*	Mean winter temperature	°C
3.	*TSp*	Mean spring temperature	°C
4.	*TSu*	Mean summer temperature	°C
5.	*TA*	Mean autumn temperature	°C
6.	*TYx*	Mean annual maximum temperature	°C
7.	*TYn*	Mean annual minimum temperature	°C
8.	*FD*	Total (annual) number of frost days—daily *Tn* < 0 °C	No. of days
9.	*ID*	ID Total number of ice days—daily *Tx* < 0 °C	No. of days
10.	*SU*	Total number of summer days—daily *Tx* ≥ 25 °C	No. of days
11.	*TD*	Total Tropical Days—Daily *Tx* ≥ 30 °C	No. of days
12.	*TR*	Total Tropical Night—Daily *Tn* > 20 °C	No. of days
13.	*Tx10*	Total number of cold days—daily *Tx* < 10-th percentile	No. of days
14.	*Tn10*	Total number of cold nights—daily *Tn* < 10-th percentile	No. of days
15.	*Tx90*	Total number of warm days—daily *Tx* > 90-th percentile	No. of days
16.	*Tn90*	Total number of warm nights—daily *Tn* > 90-th percentile	No. of days
17.	*WSDIN*	Total number of heat waves—6 and more consecutive days with daily *Tx* > 90th percentile	No. of days
18.	*GSL*	Annual count of days between the first span of at least six days where *TG* (daily mean temperature) > 5 °C and the first span in the second half of the year of at least six days where *TG* < 5 °C.	No. of days
		Precipitation	
1.	*RY*	Annual precipitation	mm (%)
2.	*RW*	Winter precipitation	mm (%)
3.	*RSp*	Spring precipitation	mm (%)
4.	*RSu*	Summer precipitation	mm (%)
5.	*RA*	Autumn precipitation	mm (%)
6.	*CDD*	Maximum no. of Consecutive Dry Days (*Rd* < 1 mm)	No. of days
7.	*CWD*	Maximum no. of Consecutive Wet Days (*Rd* ≥ 1 mm)	No. of days
8.	*R0.1*	Annual No of days with precipitation 0.1 + mm—*Rd* ≥ 0.1 mm	No. of days
9.	*R1.0*	Annual No of days with precipitation 1.0 + mm—*Rd* ≥ 1.0 mm	No. of days
10.	*R10*	Annual No of days with precipitation 10 + mm—*Rd* ≥ 10 mm	No. of days
11.	*R20*	Annual No of days with precipitation 20 + mm—*Rd* ≥ 20 mm	No. of days
12.	*R30*	Annual No of days with precipitation 30 + mm—*Rd* ≥ 30 mm	No. of days
13.	*R40*	Annual No of days with precipitation 40 + mm—*Rd* ≥ 40 mm	No. of days
14.	*R50*	Annual No of days with precipitation 50 + mm—*Rd* ≥ 50 mm	No. of days

Note. *Tx* (*n*) = daily maximum (minimum) temperature; *Rd* = daily precipitation.

For the purposes of this paper, the results of temperature and precipitation projections, according to the A1B scenario of the EBU-POM model, were analyzed for two 30-year periods for the 21st century: 2011–2040 and 2071–2100. The aim was to determine the deviations of the average values of the considered temperature and precipitation parameters of the two mentioned 30-year periods in relation to the reference period (1961–1990).

In addition to the standard mathematical-statistical methods, trend and percentiles were also used. The trend was calculated by the Sen’s slope method, and its significance was tested by the Mann-Kendall test (Kendall, 1975; Mann, 1945; Salmi, Määttä, Anttila, Ruoho-Airola, & Amnell, 2002). The World Meteorological Organization recommends (WMO, 1966), but others (Mondal, Kundu, & Mukhopadhyay, 2012) also indicate the advantage of using non-parametric tests to detect the trend of a given time series, above all Sen's slope estimates and Mann-Kendall, due to the smaller number of assumptions required for their implementation. The importance of tendency was tested at the level of risk of p < .001, .01, .05, and .10.

Results

Temperature trend in the instrumental period (1951–2018)

In the period from 1951 to 2018, the average annual temperature (*TY*) was rising at a rate of 0.24 °C/ decade—an upward trend is significant at the p < .001 level of acceptance of the hypothesis. On the seasonal level, it is interesting that summer and spring temperatures are growing faster than winter and autumn temperatures. The annual mean maximum temperature (*TYx*) rises at a trend rate of 0.27 °C/decade and the mean minimum (*TYn*) 0.23 °C/decade (Figure 2). The increasing trend of both maximum and minimum temperatures satisfies the conditions of significance to p < .001 level of hypothesis correctness. The obtained results indicate that in Kolašin the maximum and summer temperatures increase faster than the minimum and winter temperatures.

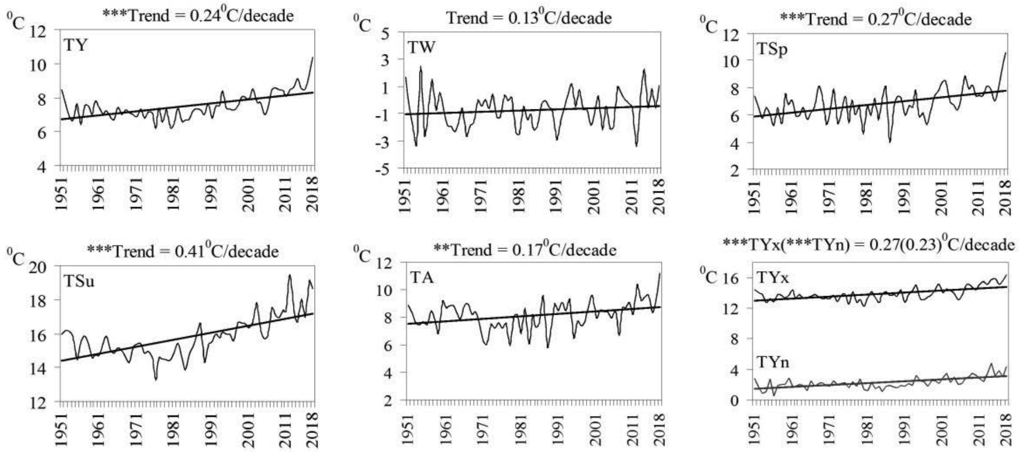
***Trend = 0.24°C/decade
Trend = 0.13°C/decade
***Trend = 0.27°C/decade
***Trend = 0.41°C/decade
**Trend = 0.17°C/decade
TYx(TYn) = 0.27(0.23)°C/decade

Figure 2. Mean temperature trend: annual (TY), winter (TW), spring (TSp), summer (TSu), autumn (TA), annual maximum (TYx) and annual minimum (TYn), Kolašin 1951–2018 (significance of trend on level: **p < .01 and ***p < .001).

The annual number of ice days (*ID*) decreases insignificantly (–0.4 days/decade). However, it should be noted that the tendency of this temperature indicator indicates the general warming trend. Frost days (*FD*), whose number is significantly decreasing over the observed 68-year period, confirm the warming—the trend is –2.3 days per decade. On the other side, the annual number of summer (*SU* = 4.7 days/decade) and tropical (*TD* = 2.1 days/decade) days is significantly increased (Figure 3).

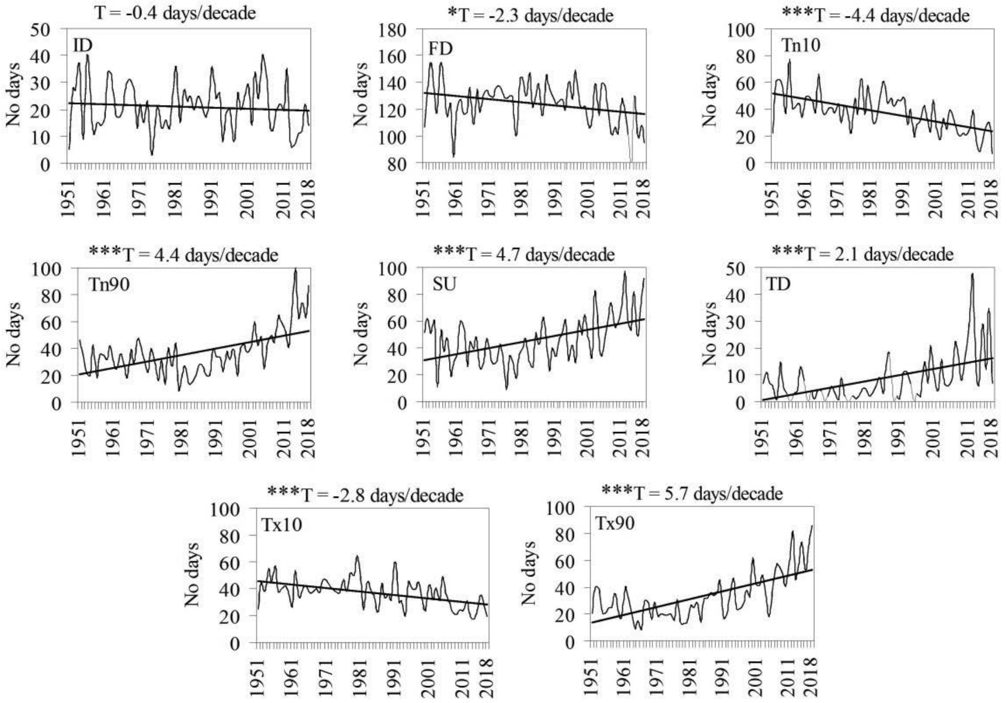

Figure 3. Trend (T) in the annual number of ice (*ID*), frosty (*FD*), summer (*SU*), tropical (*TD*), cold (*Tx10*) and warm (*Tx90*) days, respectively cold (*Tn10*) and warm (*Tn90*) nights, Kolašin 1951–2018 (significance of trend on level: **p* < .05 and ****p* < .001).

On the other side, tropical nights (*TR*) are a rare phenomenon. Probability for having at least one tropical night during summer is less than 0.5%, because it is a mountainous area (900 m above sea level and above). When it comes to percentile distribution, the presence of warming in the observed period (1951–2018) is clearly observed, as cold indices (*Tx10* and *Tn10*) show a negative trend, while warm indices (*Tx90* and *Tn90*) show a positive trend. The annual number of cold nights (*Tn10*) decreases at a rate of 4.4 days/decade. The trend of the decrease in the annual number of cold days (*Tx10*) is 2.8 days/decade. On the other hand, the annual number of warm nights and warm days (*Tn90* and *Tx90*) registers a pronounced upward trend over the observed 68-year period. The *Tn90* trend is 4.4 days/decade and the *Tx90* is 5.7 days/decade.

The graph shows that the warming trend is present from the last decade of the 20th century until the end of the period under consideration, in general. All the four indices, defined using percentile thresholds, register statistically significant changes, at $p < .001$ level of acceptance of the hypothesis. The *Tn10* index decreases more intensively than the *Tx10* index, respectively the *Tx90* is growing faster than the *Tn90* index.

Precipitation trend in the instrumental period (1951–2018)

When the precipitation is concerned, there are insignificant changes. Spring and autumn precipitation (*RSp* and *RA*) is increasing at the trend line, which is for 9.7 mm/decade, and 19.6 mm/decade, respectively. Summer and winter precipitation (*Rsu* and *RW*) decrease: –3.0 mm/decade (in summer) and –12.5 mm/decade (in winter). Given that there is a higher trend of increasing precipitation during the transition seasons compared to the trend of decreasing summer and winter, annual precipitation (RY) shows a growth trend of 0.8 mm/decade (Table 2).

Table 2
Trend of precipitation parameters in Kolašin for the period 1951–2018 (significance: + p < .1)

Parameter	Trend	Significance
RY	0.8 mm/decade (0.0%/decade)	Not
RW	–12.5 mm/decade (–1.8%/decade)	Not
RSp	9.7 mm/decade (2.0%/decade)	Not
RSu	–3.0 mm/decade (1.2%/decade)	Not
RA	19.6 mm/decade (3.0%/decade)	Not
R0.1	–0.9/decade	Not
R1.0	–1.9/decade	+
R10	–1.0/decade	Not
R20	–0.3/decade	Not
R30	0.1/decade	Not
R40	0.0/decade	Not
R50	0.3/decade	Not

Changes in the number of days with precipitation of more than 20, 30, and 50 mm (*R20, R30, R50*) are insignificant. Although the changes are insignificant, the number of days with extreme rainfall over 50 mm increases at a trend rate of 0.3 days/decade (Figure 4, left). On the other hand, the annual number of days with rainfall ≥ 1 mm (*R1*) decreases at a trend rate of –1.9 days/decade, and these changes are significant at the $p < .1$ level of the hypothesis (Figure 4, right).

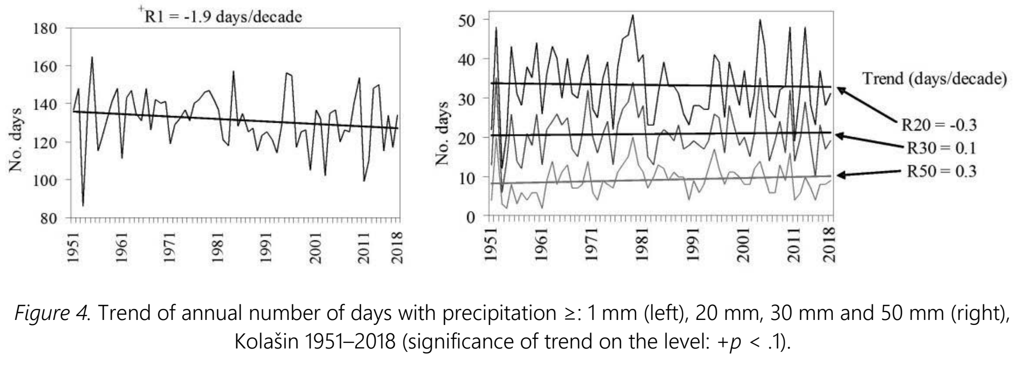

Figure 4. Trend of annual number of days with precipitation ≥: 1 mm (left), 20 mm, 30 mm and 50 mm (right), Kolašin 1951–2018 (significance of trend on the level: $+p < .1$).

Temperature projections

According to the A1B scenario, for 2011–2040, the mean annual temperature (*TY*) was expected to be 1 °C higher than for the reference period (1961–1990). The projections point (Table 3) to an increase in temperature during all the seasons, and in this period (2011–2040) the highest increase is expected for the summer season (*SU*). The mean annual minimum and maximum temperatures (*TYn* and *TYx*), according to projections, will be higher by 1.0°C and 1.4°C compared to the reference period. During this period (2011–2040), there will be a higher annual number of summer and tropical days (*SU* and *TD*). In the reference period (1961–1990), Kolašin had 20.8 ice days (*ID*) and 128.9 frost days (*FD*), and according to projections their number will decrease by -3.7 and -16.7 days respectively.

In Kolašin, days with a maximum temperature of 35 °C or more (*T35+*) are very rarely registered, but the number is expected to increase these days in 2011–2040, true very little (0.3 days). The average annual number of warm days (*Tx90*) is also expected to increase by 38 compared to the reference period. On average, for the period 1961–1990, one heat wave (*WSDIN*) is registered in Kolašin, and according to the projections in the period 2011–2040 there will be 3. The average duration of a heat wave (*WSDI*) is about 8 days, and projections indicate that in the period 2011–2040, *WSDI* will last 2 day longer.

Table 3
Projections of temperature parameters for 2011–2040 and 2071–2100 relative to the base period 1961–1990, grid field Kolašin, A1B scenario of the EBU-POM model

Parameter	Base period 1961–1990	A1B (compared to the base)	
		2011–2040	2071–2100
Mean annual temperature (*TY*) in °C	7.0	+1.0	+3.6
Mean seasonal temperature in °C			
Winter (*TW*)	–1.1	+1.1	+4.4
Spring (*TSp*)	6.5	+0.6	+2.9
Summer (*TSu*)	14.9	+1.3	+4.0
Autumn (TA)	7.7	+1.0	+3.3
Mean annual minimum temperature (*TYn*) in °C	1.9	+1.0	+3.8
Mean annual maximum temperature (*TYx*) in °C	13.5	+1.4	+4.9
Annual number of summer days (*SU*)	38.0	+21.1	+66.8
Annual number of tropical days (*TD*)	3.7	+7.8	+45.9
Annual number of tropical nights (*TR*)	0.0	0.0	+0.2
Annual number of ice days (*ID*)	20.8	–3.7	–14.8
Annual number of frost days (*FD*)	128.9	–16.7	–59.6
Annual number of days with $T \geq 35$°C (T35+)	0.1	+0.3	+10.3
Annual number of days with $T \geq 40$°C (T40+)	0.0	0.0	+0.2
Annual number of warm days (*Tx*90)	35	+38	+121
Annual Number of Heat Waves (*WSDIN*)	1	+3	+9
Annual heat wave duration (*WSDI*) in days	8	+2	+2
Annual duration of vegetation period (*GSL*) in days	223	+19	+38

Projections for the period 2071–2100 indicate significantly higher values of all the considered temperature parameters compared to the previous 30-year period (2011–2040). Therefore, the results of the EBU-POM mid-scenario (A1B) model indicate a warmer future, and by the end of the 21st century, projections will be very warm.

Precipitation projections

When it comes to precipitation, it is expected that the average annual sums (*RY*) will decrease comparing to the reference period. A1B scenario projections for 2011–2040 indicate that the *RY* will change by –125.0 mm (–5.9%), and in the period 2071–2100 by –222.4 mm (–10.5%). In the future, the average rainfall is also expected to reduce in almost all the seasons. The only exceptions are the average autumn sums (*RA*) for the period 2011–2040 and the average spring sums (*RSp*) for the period 2071–2100, which will increase by a minor 2.6 mm or 0.4%, or 8.8 mm or 1.7% in comparison with the reference period (Table 4).

Compared to the reference period (1961–1990), a longer duration of the dry period (*CDD*) is expected by 1 day in the period 2011–2040, or by 4 days in the period 2071–2100. On the other hand, the wet period duration (*CWD*) will decrease annually by one day in both periods. The annual number of precipitation days (R0.1) is also expected to fall by –14.9 (2011–2040) and –33.0 (2041–2100) days, respectively. Projections indicate that the number of days with precipitation above the other thresholds considered will decrease in the future *(R1*, *R10*, *R20*, *R30*, *R40*, and *R50*).

Table 4
Precipitation projections for 2011–2040 and 2071–2100 relative to the base period 1961–1990, grid field Kolašin, A1B scenario of the EBU-POM model

Parameter	Base period 1961–1990	A1B (compared to the base)	
		2011–2040	2071–2100
Mean annual precipitation (*RY*) in mm (%)	2122.9	–125.0 (–5.9%)	–222.4 (–10.5%)
Mean seasonal sum precipitation in mm (%)			
Winter (*RW*)	710.1	–66.6 (–9.4%)	–136.6 (–19.2%)
Spring (*RSp*)	518.3	–12.9 (–2.5%)	8.8 (1.7%)
Summer (*RSu*)	272.1	–34.8 (–12.8%)	–73.5 (–27.0%)
Autumn (*RA*)	615.0	2.6 (0.4%)	–11.6 (–1.9%)
Annual Drought Duration (*CDD*) in days	22.0	+1.0 (4.5%)	+4.0 (18.2%)
Annual wet period duration (*CWD*) in days	10.0	–1.0 (–10.0%)	–1.0 (–10.0%)
Annual number of days with *Rd* ≥ 0.1 mm (R0.1)	177.5	–14.9 (–8.4%)	–33.0 (–18.6%)
Days a day with *Rd* ≥ 1.0 mm (*R1*)	130.2	–14 (–10.8%)	–24.6 (–18.9%)
Days a day with *Rd* ≥ 10 mm (*R10*)	56.8	–5.4 (–9.5%)	–9.0 (–15.8%)
Days a day with *Rd* ≥ 20 mm (*R20*)	32.7	–2.4 (–7.3%)	–4.0 (–12.2%)
Days a day with *Rd* ≥ 30 mm (*R30*)	20.7	–1.0 (–4.8%)	–0.8 (–3.9%)
Days a day with *Rd* ≥ 40 mm (*R40*)	13.9	–0.4 (–2.9%)	0.0 (0.0%)
Days a day with *Rd* ≥ 50 mm (*R50*)	9.5	0.0 (0.0%)	–0.1 (–1.1%)

Generally, projections of the EBU–POM model for the A1B scenario indicate that in the future, fewer precipitation days should be counted on and fewer rainfall days in the grid field to which Kolašin belongs. In most cases, significantly larger changes in the considered precipitation parameters are expected by the end of the 21st century (2071–2100). For example, in the period 2071–2100, the most intense precipitation decrease is expected in the summer season, as much as –27.0%, and the annual number of days with precipitation ≥ 1mm (R1) in this period will decrease by about 25 days (–24.6 days).

Discussion

In the area of the Mediterranean and of Southeastern Europe increasingly frequent weather extremes are registered (Burić, Doderović, Dragojlović, & Penjišević, 2020; Mostafa et al., 2019; Stagge, Kingston, Tallaksen, & Hannah, 2017). Projections indicate (Hochman, Harpaz, Saaroni, & Alpert, 2018) that this region will continue to be affected by significant warming and reduced precipitation in the future. Due to the domination of the anthropogenic greenhouse effect, simulations indicate a more intense increase of minimum than maximum temperature. Globally, research results confirm it (Donat & Alexander, 2012), so there is an intense trend of increasing minimum rather than maximum temperatures. Similarity is also observed at the regional level. For example, looking at Europe as a whole (Klein Tank & Können, 2003), then South America (Skansi et al., 2013), China (Yu & Li, 2015), as well as the southeastern United States (Powell & Keim, 2015), study results show a more intense increase of indices associated with minimum rather than maximum temperatures.

However, the results presented in the paper showed an intense upward trend of maximum rather than minimum temperature in Kolašin during the instrumental period (1951–2018). Not only is it happening on the territory of Montenegro (Burić & Doderović, 2020; Burić, Ducić, & Mihajlović, 2018), but similar results have been obtained and in other parts of the Western Balkans, e.g., on the territory of Bosnia and Herzegovina (Popov, Gnjato, Trbić, & Ivanišević, 2018). In the area of neighboring Serbia, the trends in the duration of extreme temperature conditions were most pronounced in the summer season (Malinovic-Milicevic, Radovanovic, Stanojevic, & Milovanovic, 2016).

According to the A1B scenario, by the end of the 21st century, in the grid field to which Kolašin belongs, a more intensive increase in parameters related to summer and maximum temperature compared to winter and minimum temperature, in general, should be considered. In other words, the results for Kolašin, both in the instrumental period and in terms of projections, are inconsistent with the theory of dominance of the anthropogenic greenhouse effect. This does not mean that this effect does not exist, but rather indicates the complexity of identifying possible causes of changes in temperature, precipitation and other climate elements, especially at the local level.

The results for Kolašin, concerning precipitation, do not indicate any significant changes during the instrumental period (1951–2018). Burić and Doderović (2019) point out that no significant precipitation changes were obtained in the southern part of Montenegro (Podgorica). Projections of the EBU-POM model for the A1B scenario indicate that in the future, one should count on a smaller amount of precipitation and a larger number of days without precipitation in the grid field to which Kolašin belongs.

Despite the fact that the projections of different models deviate (Holtanová, Mendlik, Koláček, Horová, & Mikšovský, 2019), climate models are useful and projections need to be taken seriously, as they indicate what the future may look like if we continue our irresponsible behavior towards environment. Montenegro is a spatially small country, with a poorly developed economy, so it has no impact on global climate events. However, one has to think globally and work locally, so the results obtained in this paper can serve decision-makers to take some measures to adapt and mitigate climate changes, especially in the agriculture, tourism, water management, and architecture sectors.

Conclusions

The results for Kolašin presented in this paper indicate that its climate is becoming warmer and with more frequent temperature extremes in the positive direction. In the instrumental period (1951–2018), the mean summer temperature (*TSu*) rises much faster than the mean winter (*TW*) temperature: trend *TSu* = 0.41 °C/decade and *TW* = 0.13 °C/decade. The annual mean maximum temperature (*TYx* = 0.27 °C/decade) recorded a more intense increase than the mean annual minimum temperature (*TYn* = 0.23 °C/decade). Also, almost all the indices related to the maximum temperature show a more intense upward trend than the tendency of indices that take into account the minimum temperature. Precipitation changes do exist (*RY, RW, RSp, Rsu,* and *RA*), but in most cases they are insignificant. However, it should be noted that in the instrumental period (1951–2018), the climate of Kolašin became a little more extreme in terms of rainfall days—rainfall days are less frequent (*R0.1, R1, R10,* and *R20*), but true, slightly, the number of days with extreme rainfall (*R30* and *R50*) increased.

When it comes to the future, the projections by EBU-POM model, forced by Scenario A1B, indicate a warmer future and very warm end of the 21st century. Compared to the reference period (1961–1990), it is expected that in the period 2071–2100 *TY* will be higher by 3.6 °C, as well as an increase in the annual number of *SUs* and *TDs* by 66.8 and 45.9 days. Compared to the reference period, it is expected that in the period 2071–2100 TYn and *TYx* will increase by +3.8 °C and +4.9 °C, respectively. An increase in the annual number of heat waves (*WSDIN* = +9) and their longer duration (*WSDI* = +2 days) is projected for this period. In the area of the grid field to which Kolašin belongs, at the end of the 21st century projections indicate a significantly higher number of *Tx90* (+121 days) compared to the reference period, as well as a longer duration of the vegetation period (*GSL* = +38 days). In the period 2071–2100, according to the A1B scenario, compared to the reference period, a decrease in the average annual precipitation (*RY* = –10.5%) is expected, while the dry (wet) period will last longer (shorter) (*CDD* = +4 days and *CWD* = –1 day). The projected reduction of the annual number of almost all the considered precipitation days (*R0.1, R1, R10, R20, R30, R40,* and *R50*) also implies that a slightly more arid future is expected. So the projections point to a slightly more arid but warmer future with more frequent extreme temperatures in the positive direction.

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