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Projected temperature changes in Kolašin (Montenegro) up to 2100 according to EBU-POM and ALADIN regional climate models

Dragan Burić* and Miroslav Doderović

*Department of Geography
Faculty of Philosophy, Nikšić
University of Montenegro
Cetinjski put 2, 81000 Podgorica, Montenegro*

**Corresponding author E-mail: buric.d@ucg.ac.me (dragan.buric@meteo.co.me)*

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Abstract— This paper deals with the temperature projections of two regional climate models, actually three scenarios by 2100: the A2 scenario of the EBU-POM model and the RCP4.5 and RCP8.5 scenarios, the latest projections of the ALADIN model. Kolašin was chosen, because the altitude of the place is the average height of the northern region of Montenegro (about 1000 m). A total of 22 temperature parameters for the period 2011–2100 were analyzed. The upward trend of projected seasonal and annual (TY, TY_x, and TY_n) mean, mean maximum, and mean minimum temperatures by 2100 is very significant. According to the RCP4.5 and RCP8.5 scenarios, in 2011–2100, the trend of projected mean winter (TW) temperatures will be from 0.2 to 0.37 °C per decade, and the trend of projected mean summer (TSu) temperatures will be from 0.24 to 0.54 °C per decade. Compared to the base period (1981–2010), the average annual temperature in 2071–2100 is expected to be higher than 2.2 (RCP4.5) to 3.6 °C (A2 and RCP8.5). Also, by the end of the 21st century, a significant increase in the number of summer and tropical days (SD and TD) together with a decrease in the number of frost and ice days (FD and ID) are expected. During the instrumental period, a temperature higher than 37 °C was not recorded. According to projections, in the late 21st century, in summer, maximum temperatures of 40 °C are possible, even in the milder variant (RCP4.5) scenario. According to projections of the used models, Kolašin and the northern region of Montenegro expect a warmer future with more frequent extreme temperatures in a positive direction.

Key-words: temperature, projections, EBU-POM, ALADIN, scenarios A2, RCP4.5, RCP8.5, Kolašin, Montenegro

1. Introduction

Since the mid-20th century, the Mediterranean region has recorded a significant rise in air temperature. Also the Mediterranean Sea registers an increase in the surface water temperature. Satellite data indicate that from 1985 to 2006, the increase in surface water temperature was slightly more intense in the eastern than in the western regions of the Mediterranean Sea. The maximum increase in water temperature, 0.16 °C per year, was recorded in June in the Adriatic, Ligurian, and Tyrrhenian Seas (*Nykjaer, 2009*). The increase in temperature has led to greater evaporation causing an increase in dryness in the Iberian Peninsula in the last five decades (*Vicente-Serrano et al., 2014*).

Projections for the 21st century indicate that the Mediterranean (*Mostafa et al., 2019*) and southeastern parts of Europe (*Hochman et al., 2018a*) will be affected by significant warming and precipitation. According to the RCP8.5 scenario for the Eastern Mediterranean, it is projected that at the end of the 21st century, the duration of the synoptic summer will be 49% longer, and the synoptic winter will be shorter by 56% (*Hochman et al., 2018b*). As a result of the many contrasts (the collision of air masses from the north and the south, land-sea-atmosphere interactions, relief disaggregation), the Mediterranean region is often chosen to test new regional climate modeling tools (*Sevault et al., 2014; Nabat et al., 2015*).

Based on the model ensemble, both scenarios (RCP4.5 and RCP8.5) predict that Mediterranean Europe and the northeastern parts of the continent will heat up most intensively during the 21st century. In the Mediterranean area, annual rainfall is expected to decrease by up to 25% (*Jacob et al., 2014*). However, studies show that in Western Europe, the trend of temperature rise in 1950-2008 was much faster than projected by individual models (*Van Oldenborgh et al., 2009*). The expected rise in temperature and the likely increase in dryness in the Mediterranean region are thought to have serious consequences on ecosystems and local populations (*Lelieveld et al., 2016; Bucchignani et al., 2018*).

The Intergovernmental Panel on Climate Change (*IPCC, 2014*) points out that the human impact on climate is clear, primarily in the form of increased concentrations of greenhouse gases in the atmosphere. The fifth IPCC report, as previous reports, says that many regions of the world have recorded changes in the intensity and frequency of extreme weather events such as: droughts, floods, extreme temperatures, heat waves, stormy weather followed by the hail, heavy short-term rains, etc. It is also noted that the increased incidence of extreme weather events should also be possible during the 21st century, but significant regional variations are expected, especially with regard to precipitation. According to the IPCC, among other things, the entire Mediterranean region, the southeastern parts of Europe, and the Middle East are considered potential hotspots of climate change in the future.

According to an extensive study by the French National Alliance for the Environment (Alliance nationale de recherche pour l'environnement – AllEnvi), the Mediterranean is one of the most vulnerable regions to climate change in the world. GCM and RCM simulations for the Mediterranean region indicate that the trend of warming and drying is likely to continue in the future, but that there are uncertainties in the spatial distribution, especially in precipitation (AllEnvi, 2016). That is why the mentioned study emphasizes the importance of research on smaller spatial units – subregions and individual locations of the Mediterranean. A similar observation is made in the study by *Giorgi* (2006) and *Adloff et al.* (2015).

The first four reports of the Intergovernmental Panel on Climate Change (IPCC) used SRES emission scenarios (*Nakicenovic et al.*, 2000). The IPCC Fifth Assessment Synthesis Report (IPCC, 2014) uses the results of regional climate models. RCMs use the so-called representative concentration pathways (RCPs), which take climate change mitigation and adaptation into account and define the increase in radiation energy depending on the CO₂ concentration trend by 2100 (*Moss et al.*, 2010).

RCPs take into account different mixtures of greenhouse gas and aerosol emissions on the one hand and climate protection measures on the other. Scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5 are in use, and the number in the suffix indicates the radiation sensitivity with respect to the pre-industrial period. RCP2.6 is a scenario indicating a slight variant of energy gain (2.6 W/m²), RCP4.5 is a moderate scenario (energy increase of 4.5 W/m²), RCP6.0 is a moderately high variant (6.0 W/m²), and RCP8.5 is an extreme or very high variant that takes into account the heating of an 8.5 W/m² air-conditioning system. The main difference between the extreme scenarios is that the RCP8.5 variant implies economic growth based on fossil fuel combustion, while the RCP2.6 is optimistic as it takes into account global climate protection efforts. According to the RCP4.5 scenario, which is in line with the 2015 Paris Agreement, the average global temperature will rise by 1.6 °C by the end of the century (range between 1.1 and 2.6 °C), and according to RCP8.5, which takes into account the current trend CO₂, the average rise in global temperature will be around 3.7 °C (2.6–4.8 °C). A comparative overview of the SRES and RCP emission scenarios is in *Table 1* (*Chimani et al.*, 2016).

The main objective of this research is to analyze several temperature parameters according to the projections of two regional climate models (RCMs), the EBU-POM and ALADIN models for scenarios A2, RCP4.5, and RCP8.5. The used models will be discussed in more detail in subtitle 2.2. After the introductory part (Section 1), the research area, databases, and methodology (Section 2) are described, the results of the EBU-POM model for A2 scenario and of the ALADIN model for RCP4.5 and RCP8.5 simulations are presented in Section 3, followed by the discussion (Section 4) and conclusion (Section 5).

Table 1. Comparison of SRES and RCP emission scenarios (Source: *Chimani et al.*, 2016)

SRES	RCP	Description (by 2100):
A2	RCP8.5	A2: Constant population increase, further economic growth, regional, slower technological change than in other scenarios. RCP8.5: Over 1370ppm CO ₂ equivalent concentration by 2100.
A1B	RCP6.0	A1B: Increased economic growth, slower population growth, usage of new and more efficient technologies, reduction of regional income disparities, balanced usage of all energy sources (not too dependent on a particular energy source), etc. RCP6.0: Slower greenhouse radiation effect growth, around 850 ppm CO ₂ equivalent concentration by 2100
B1	RCP4.5	B1: Global population peak in the mid-21st century, followed by a decrease, rapid change in economic structures towards the development of services and information technologies, introduction of a clean economy and clean energy sources, global environmental, economic, and social sustainability, etc. RCP4.5: The rise in CO ₂ emissions peaks around 2040, then the emission decreases, and in 2100 the atmospheric concentration of greenhouse gases will be about 650 ppm CO ₂ -equivalent.

2. Research area, models used, databases and methodology

2.1. Research area

Montenegro is a Mediterranean country. Covering an area of 13 812 km² it belongs to Southeastern Europe (Western Balkans), extending over 100 km (air distance) to the Adriatic Sea. The study covers the area of Kolašin, a town which belongs to the northern region of Montenegro. The main factors that influence the formation of the Kolašin climate are: its latitude, air currents, and relief.

The urban area is located at 1000 m above sea level while the weather station is at 944 m above sea level (*Burić et al.*, 2013). According to the Köppen climate classification, the urban areas and lower terrains have characteristics of moderately continental climate (climate formula Csbx '), while higher mountain areas have characteristics of moderately cold climate (climate formula D) (*Burić et al.*, 2014). Kolašin is located in the upper part of the Tara River valley, surrounded by mountain ranges of Sinjajevina and Bjelasica, whose peaks exceed 2000 m (*Fig. 1*).



Fig. 1. Location of Montenegro in the Mediterranean region and Kolašin in Montenegro (Kolašin: latitude = $42^{\circ}49'22''\text{N}$, longitude = $19^{\circ}31'4''\text{E}$, altitude = 944 m)

2.2. Models used

Djurđević and *Rajković* (2010) developed a dynamically adapted RCM for the Mediterranean region of Europe, EBU-POM model. It is a fully coupled atmospheric-ocean model. The atmospheric part of the model is a version of the state-of-the-art atmospheric model ETA of the National Centers for Environmental Protection (NCEP), and the ocean part is the Princeton Ocean Model (POM). Based on the results of future climate change scenarios obtained by EBU-POM, a database was created for individual parts and locations for Mediterranean Europe. The oceanic part of the model covers the area of the Mediterranean Sea, but without the Black Sea. The horizontal resolution of EBU-POM model is 25 km, while in the vertical direction the model has 32 levels. The EBU-POM model for initial and boundary simulation conditions uses the results of the ECHAM5 global climate model (GCM) (*Roekner et al.*, 2003), together with the MPI-OM ocean model. Professor Đurđević completed the correlation for the A2 scenario and gave us the data for the grid field to which Kolašin belongs.

The Institute of Meteorology and Climatology of the University of Natural Resources and Life Sciences, Vienna (BOKU-Met) evaluated the available regional climate change projections (EURO-CORDEX, MED-CORDEX) comparing them with observational data, and generated an ensemble of bias-corrected climate change scenarios for the Western Balkan Region. For bias

correction BOKU-Met developed and used a program called ICC-OBS Tool (*Formayer et al.*, 2019). Bias correction algorithms are based on observations, and the model data is modified so that its statistical properties become the same as those of observations. The climate change signals are calculated with reference to the period 1981–2010. After numerous corrections, from June 2019, data for the Western Balkans National Meteorological Services are available through the Climate Change Center Austria (CCCA).

Studies have shown that ALADIN-Climat v5, developed in CNRM/Météo-France, can be successfully used for Central and Eastern Europe, and for temperature and precipitation simulations in the Balkans, where Bulgaria were considered as an evaluation area (*Farda et al.*, 2010). It can also be used for the Balkans and the Apennines (*Spiridonov and Valcheva*, 2019), as well as for the Morocco area (*Tramblay et al.*, 2013). Related to that and for the purposes of this study, RCM ALADIN data, which uses the GCM CNRM-CM5 results as boundary and lateral conditions, were also analyzed. The resolution of the Aladin model is 0.11° (about 12.5 km).

2.3. Database and methodology

For the purposes of this study, the data of two RCMs and three scenarios were considered. The data for Kolašin's EBU-POM model for scenario A2 were obtained from Professor Djurdjevic (author of the model). The ALADIN model data for RCP4.5 and RCP8.5 scenarios for Kolašin were obtained from the Climate Change Center Austria (CCCA). Based on historical observational data for Kolašin, simulations were made for the base period 1981–2010, and projections were given for the period 2011–2100 based on these simulations. In accordance with the horizontal resolution of the models used, the projected data refer to the grid field to which Kolašin belongs.

The trend was calculated by the Sen method, and its significance was tested by the Mann-Kendall test. Importance of tendency was tested at the risk level of $p < 0.001$, $p < 0.01$, $p < 0.05$, and $p < 0.1$ (the degree of accuracy of the hypothesis of 99.9%, 99%, 95% and 90%). A total of 22 temperature parameters were considered in this study (*Table 2*).

The climatic period 1981–2010 was taken as reference (base) period, and the results of simulation of the projected temperature in Kolašin were given for the period 2011–2100. The 30-year periods for the 21st century were separated, and for each the mean value, i.e., the deviation from the base period (1981–2010) was calculated. In addition the trend for the period 2011–2100 was also calculated.

Table 2. Abbreviations, definitions, and units of the used temperature parameters

No.	Index	Definition	Unit
1.	TY	Mean annual temperature	°C
2.	TW	Average winter temperature	°C
3.	TSp	Mean spring temperature	°C
4.	TSu	Mean summer temperature	°C
5.	TA	Average autumn temperature	°C
6.	TYx	Mean annual maximum temperature	°C
7.	TWx	Mean winter maximum temperature	°C
8.	TSp _x	Mean spring maximum temperature	°C
9.	TSu _x	Mean summer maximum temperature	°C
10.	TA _x	Mid-autumn maximum temperature	°C
11.	TY _n	Mean annual minimum temperature	°C
12.	TW _n	Mid-winter minimum temperature	°C
13.	TSp _n	Mean spring minimum temperature	°C
14.	TSu _n	Mean summer minimum temperature	°C
15.	TA _n	Mid-autumn minimum temperature	°C
16.	FD	Total number of frost days - daily T _n < 0 °C	number of days
17.	ID	Total number of ice days - daily T _x < 0 °C	number of days
18.	SU	Total number of summer days - daily T _x ≥ 25 °C	number of days
19.	TD	Total Tropical Days - Daily T _x ≥ 30 °C	number of days
20.	TR	Total tropical nights - daily T _n > 20 °C	number of days
21.	35+	Total number of days with a maximum temperature of 35 degrees or higher (T _x ≥ 35 °C)	number of days
22.	40+	Total number of days with a maximum temperature of 40 degrees or higher (T _x ≥ 40 °C)	number of days

T_x (n) - daily maximum (minimum) temperature

3. Results

3.1. Results of the EBU-POM model for A2 scenario

According to the A2 projections of the EBU-POM model scenario, the mean annual temperature (TY) will be higher by 0.5 °C in the period 2011–2040, by 1.7 °C in 2041–2070, and by 3.6 °C in 2071–2100 compared to the base period (1981–2010). At the seasonal level, the most intense increase of mid-winter (TW) and mid-summer (TSu) temperatures is expected. In qualitative terms, the same results were obtained for both the annual mean maximum (TY_x) and minimum (TY_n) temperatures. According to these projections, a more intense increase of the maximum than the minimum temperature is expected. It is noted that the further the future goes, the more intensively the temperature increases.

Thus, the most intense increase in temperature is expected for the last 30-year period (2071–2100). Compared to the base period (1981–2010), projections indicate that TYn will be 3.8 °C higher, while TYx will be 5.0 °C higher in 2071–2100. The expected increase in the summer temperature parameters in Kolašin in the period 2071–2100, according to the A2 scenario, will be the following: TSu will be higher by 3.6 °C, TSun by 3.5 °C, and TSux by 5.4 °C (Table 3). If these projections do come true, by the end of the 21st century, Kolašin will be extremely hotter than nowadays.

Table 3. Projections of mean annual and seasonal temperatures (°C) for 2100 in Kolašin, relative to the 1981–2010 base period, based on the A2 scenario of the EBU-POM model

T (°C)	Base period	A2 scenario		
	1981–2010	2011–2040	2041–2070	2071–2100
Avg.T	1981–2010	2011–2040	2041–2070	2071–2100
TY	7.4	+0.5	+1.7	+3.6
TW	–1.1	+1.1	+2.1	+3.8
TSp	6.5	+0.6	+1.2	+3.0
TSu	14.9	+0.8	+1.6	+3.6
TA	7.7	+0.4	+1.4	+3.2
Avg.Tn	1981–2010	2011–2040	2041–2070	2071–2100
TYn	2.3	+0.6	+1.8	+3.8
TWn	–5.0	+1.3	+2.5	+4.2
TSpn	1.3	+0.5	+1.1	+2.9
TSun	8.5	+0.9	+1.6	+3.5
TAn	2.8	+0.5	+1.6	+3.5
Avg.Tn	1981–2010	2011–2040	2041–2070	2071–2100
TYx	14.0	+0.6	+2.2	+5.0
TWx	3.5	+1.3	+2.3	+4.3
TSpx	12.7	+0.8	+1.6	+4.1
TSux	22.9	+1.1	+2.3	+5.4
TAx	14.7	+0.6	+1.8	+4.4

Avg.T – average; Avg.Tn(Tx) – average max (min) temperature

Also, days with characteristic temperatures indicate a warmer future. In 2011–2040, the annual number of summer days (SU) will be 9.1 days higher than in the base period. During 2041–2070, the projected average annual number of SUs will be 29.2 days higher than in 1981–2010. According to projections, in 2071–2100 Kolašin will have an average of 66.9 SU annually, more than in the

base period. In the last 30-year period (2071–2100), there will be about 50 tropical days (50.3 TD), more than in the base period. After 2070, tropical nights (TR) are possible in Kolašin, which is 1 tropical night in certain years. During the instrumental period, days with a maximum temperature above 35 °C were rarely recorded. However, the projected number of days with a maximum temperature above 35 °C (35+) in 2071–2100 is about 12–13 days a year. During the instrumental measurement period (1949–present), no temperature of 40 °C or higher (40+) was recorded in Kolašin. However, projections show that after 2070, summer maximum daily temperatures above 40 °C will be possible, one day per year. On the other hand, frost and ice days (FD and ID) will occur less frequently by 2100. In the average year, Kolašin registers about 122 FD, and projections for the period 2071–2100 indicate that this number will decrease by as much as 59.5 days (*Table 4*).

Table 4. Projections of the annual number of days with temperatures above fixed thresholds by 2100 in Kolašin, relative to the 1981–2010 base period, based on the A2 scenario of the EBU–POM model

Number days	Base period	A2 scenario		
	1981–2010	2011–2040	2041–2070	2071–2100
SU	44.3	+9.1	+29.2	+66.9
TD	5.1	+4.6	+17.7	+50.3
TR	0.0	0.0	0.0	+0.5
ID	17.6	–0.4	–7.4	–12.7
FD	122.1	–14.0	–29.9	–59.5
35+	0.2	0.0	+1.4	+12.7
40+	0.0	0.0	0.0	+0.5

The trend component is the basic direction of movement of a given climate element and an excellent indicator of changes over a longer period of time. Therefore, the trend of individual air temperature parameters was calculated for the purposes of the study. The calculations show that the trend of temperature increase is fairly uniform: from 0.46 °C (TSp) to 0.52 °C (TSu and TA) per decade. The tendency for an increase in projected mean temperature during the 21st century is significant at the highest level of confidence ($p < 0.001$): 99.9% of the level of acceptance of the hypothesis, both annually and seasonally (*Fig. 2*). By the end of the 21st century, the expected trend of increase in the mean annual temperature (TY) mean winter temperature (TW) is 0.51 °C per decade.

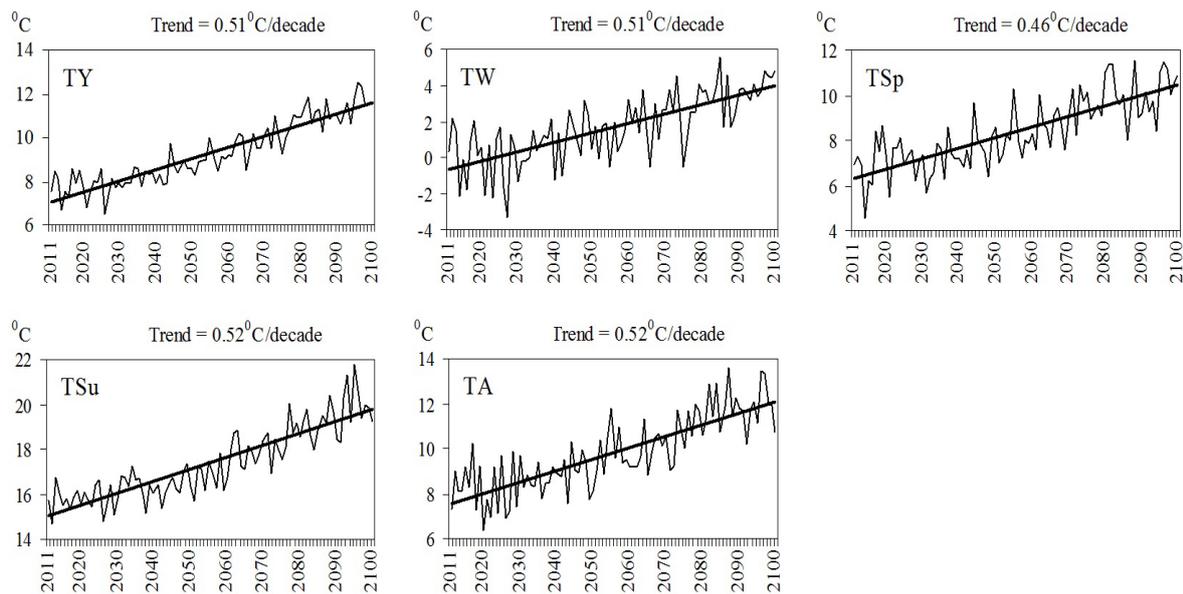


Fig. 2. Trend of the mean temperatures: annual (TY), winter (TW), spring (TSp), summer (TSu) and autumn (TA), at the significance level of $p < 0.0001$, in Kolašin in the period 2011–2100 based on the A2 scenario of the EBU-POM model.

A trend project for the average annual minimum and maximum temperatures (TYn and TYx) in 2011–2100 is statistically very significant (risk of accuracy 0.001). The trend of increasing TYx (0.72 °C per decade) is more pronounced than TYn (0.52 °C per decade) (Fig. 3).

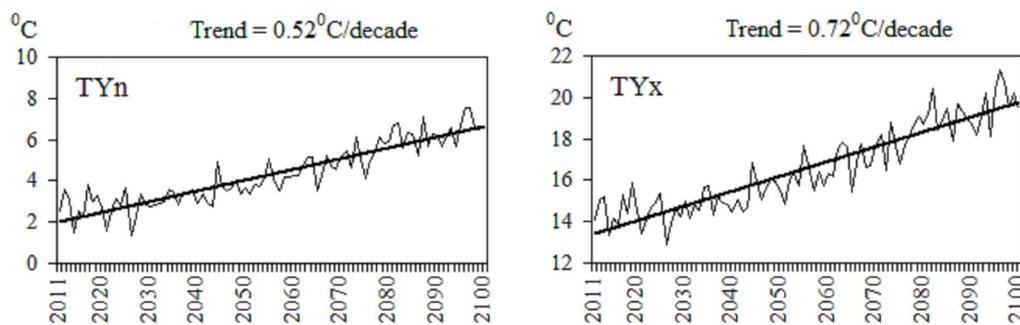


Fig. 3. Trend of the projected average annual minimum (TYn) and maximum (TYx) temperatures at the significance level of $p < 0.0001$, in Kolašin in the period 2011–2100 based on the A2 scenario of the EBU-POM model.

3.2. Results of the ALADIN model for RCP4.5 and RCP8.5 scenarios

Recently, RCMs have been using RCP scenarios. Following current trends, the results of the ALADIN model are given below for the same temperature parameters, which were examined by the EBU-POM model in the previous section. A moderate variant (RCP4.5) was also considered, not only an extreme (RCP8.5) as in the previous model (A2). According to the RCP4.5 scenario, all temperature parameters show a warmer future. Therefore, even in a moderate scenario, the temperature in Kolašin is expected to increase by the end of the 21st century. In the period 2071–2100, the projected mean spring temperature (TSp) will be 2.4 °C higher than in the base period and the mean autumn (TA) will be higher by 1.9 °C (Table 5, left). For the same period (2071–2100), projections indicate that both maximum and minimum temperatures will rise the fastest in spring – TSpn by 2.6 °C and TSpx by 2.3 °C compared to the base period (1981–2010).

Table 5. Projections of the mean annual and seasonal temperatures (°C) by 2100 in Kolašin, relative to the 1981–2010 base period, based on the RCP4.5 and RCP8.5 scenarios of the CNRM-ALADIN53 model

T (°C)	Base period	Scenario RCP4.5			Scenario RCP8.5		
	1981–2010	2011–2040	2041–2070	2071–2100	2011–2040	2041–2070	2071–2100
Avg. T	1981–2010	2011–2040	2041–2070	2071–2100	2011–2040	2041–2070	2071–2100
TY	9.3	+0.7	+1.4	+2.2	+0.8	+2.1	+3.6
TW	0.8	+0.8	+1.2	+2.0	+0.9	+2.0	+3.2
TSp	8.0	+0.9	+1.2	+2.4	+1.0	+2.2	+3.7
TSu	18.0	+0.9	+1.9	+2.2	+0.9	+2.1	+4.2
TA	10.4	+0.3	+1.2	+1.9	+0.5	+2.0	+3.2
Avg. Tn	1981–2010	2011–2040	2041–2070	2071–2100	2011–2040	2041–2070	2071–2100
TYn	4.6	+0.7	+1.4	+2.2	+0.8	+2.1	+3.7
TWn	–3.0	+0.8	+1.2	+1.9	+0.7	+1.8	+2.9
TSpn	3.4	+0.9	+1.2	+2.6	+0.8	+2.4	+3.9
TSun	12.4	+0.9	+1.9	+2.3	+1.0	+2.3	+4.4
TAn	5.7	+0.2	+1.2	+1.9	+0.7	+2.0	+3.3
Avg. Tx	1981–2010	2011–2040	2041–2070	2071–2100	2011–2040	2041–2070	2071–2100
TYx	13.9	+0.7	+1.4	+2.1	+0.9	+2.0	+3.5
TWx	4.6	+0.9	+1.3	+2.1	+1.0	+2.1	+3.4
TSpx	12.5	+0.8	+1.1	+2.3	+1.1	+2.1	+3.6
TSux	23.6	+0.9	+1.8	+2.2	+0.9	+1.9	+3.9
TAx	15.0	+0.3	+1.2	+1.9	+0.4	+1.9	+3.1

T- Avg. T - average temperature; Avg. Tn(Tx) - average max (min) temperature

The more extreme variant (RCP8.5) is expected to have a more intense temperature rise in Kolašin. In 2071–2100, according to the estimates of the RCP8.5 scenario, the summer temperature will grow the most rapidly: TSu will be higher by 4.2°C, TSun by 4.4 °C, and Tsux by 3.9 °C compared to the base period (*Table 5*, right). Thus, estimates indicate that the minimum temperature will grow more intensively than the maximum temperature. The only exception is the mean winter maximum temperature (TWx), which will under this scenario than that of increase (+3.4 °C) have a higher the mean winter minimum (TWN) temperature (+2.9 °C) in 2071–2100.

Comparing the results of A2 and RCP8.5 scenarios for the period 2071–2100, the projections of the EBU-POM model give a higher increase in the mean maximum temperatures (TYx, TWx, TSp_x, TSux, and TA_x) compared to the ALADIN model. When it comes to the mean and average minimum temperature for the mentioned period (2071–2100), the EBU-POM model gives a slight increase only in spring and summer compared to the ALADIN RCP8.5 scenario. At annual level, as well as in winter and autumn, the situation is reversed.

Specific day projections also indicate a warmer future, even under the RCP4.5 scenario. The moderate scenario (RCP4.5) estimates that in 2011–2040, the average number of summer days (SUs) will increase by 9.8 days compared to the base period (1981–2010). In 2041–2070, the number of SUs will be increased by about 20, and in the period 2071–2100 by 26.7 days. The number of tropical days and nights (TD and TR) is also expected to increase, followed by days with a maximum temperature above 35 °C and 40 °C (35+ and 40+). The expectation of a warmer future is also indicated by the decrease in the number of ice and frost days (ID and FD). According to the RCP4.5 scenario, for the period 2071–2100, the average annual FD number will be 23.4 days lower than in the base period (*Table 6*).

Table 6. Projections of the annual days with temperatures above fixed thresholds by 2100 in Kolašin, relative to the 1981–2010 baseline period, based on the RCP4.5 and RCP8.5 scenarios of the CNRM-ALADIN53 model

Number of days	Base period 1981–2010	Scenario RCP4.5			Scenario RCP8.5		
		2011–2040	2041–2070	2071–2100	2011–2040	2041–2070	2071–2100
SU	36.7	+9.8	+20.0	+26.7	+10.8	+20.6	+45.4
TD	4.2	+4.2	+9.1	+11.2	+2.1	+9.7	+23.2
TR	0.1	+0.4	+1.2	+1.3	0.0	+2.1	+10.2
ID	15.9	-1.3	-4.7	-8.2	-3.0	-7.1	-9.8
FD	93.3	-11.1	-14.2	-23.4	-7.0	-22.0	-33.1
35+	0.0	+1.0	+1.6	+1.5	+0.4	+2.6	+6.0
40+	0.0	0.0	0.0	+0.1	0.0	0.0	+0.9

ALADIN's more extreme RCP8.5 scenario predicts more intense changes to the days mentioned. According to this scenario, in the last 30-year period of the 21st century (2071–2100), the number of SUs is expected to be 45.4 days more than in the base period. In the period 2071–2100, RCP4.5 predicts 1–2 days with a temperature of 35+ per year, and RCP8.5 predicts about 6 such days. It has already been mentioned that for the period 2071–2100, according to the A2 scenario, the average annual number of days with a temperature of 35+ is expected to be twofold of the number calculated by the RCP8.5 projections. In most other specific days, more intensive changes are expected under the A2 scenario than under RCP8.5.

In 2011–2100, the average annual temperature increase is expected to be 0.25 °C per decade according to the RCP4.5 scenario, or 0.48 °C per decade according to RCP8.5. At the seasonal level, according to the RCP4.5 scenario, a more intense trend of increasing mean temperatures is expected in spring and autumn (TSp and TA) than in winter and summer (TW and TSu). For the period 2011–2100, the expected trend is 0.28 °C increase for TSp and 0.29 °C for TA per decade, while the projected TW and TSu are 0.20 °C and 0.24 °C per decade, respectively (Fig. 4). According to the more extreme variant (RCP8.5), by the end of the 21st century, a more intense upward trend in TSu and TA (0.54 °C and 0.50 °C per decade) is expected than in TW and TSp (0.37 °C and 0.47 °C per decade). The projections of both scenarios (RCP4.5 and RCP8.5), according to the Mann-Kendall test, indicate that we should expect a significant trend of temperature increase for the observed period (2011–2100), both on annual and seasonal levels. Even the RCP4.5 scenario projects a 99.9% ($p < 0.001$) positive momentum level by the end of the 21st century.

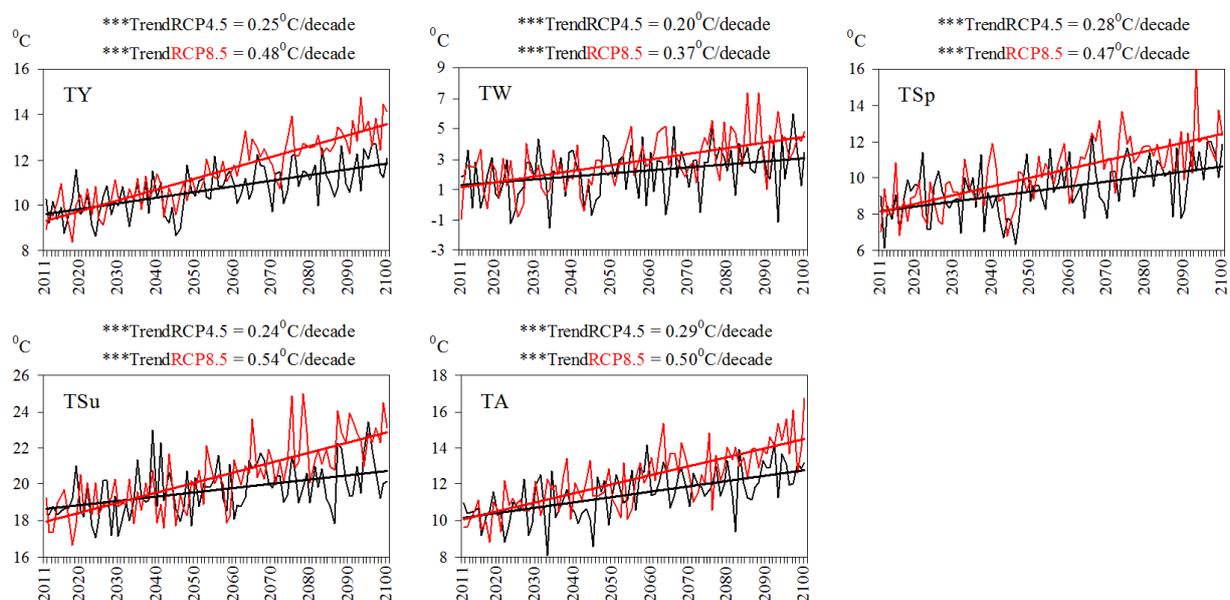


Fig. 4. Trend of average temperatures: annual (TY), winter (TW), spring (TSp), summer (TSu), and autumn (TA), at the significance level of $p < 0.0001$, in Kolašin in the period 2011–2100 based on the RCP4.5 and RCP8.5 scenario of CNRM-ALADIN53 model.

Also, projections of both scenarios indicate that a significant upward trend in mean annual maximum and minimum temperatures should be expected by 2100. According to the milder variant (RCP4.5), the mean annual minimum (TYn) and maximum (TYx) temperatures increase at a trend rate of 0.25 °C per decade (Fig. 5). A more extreme scenario (RCP8.5) predicts a slightly more intense increase in TYn than TYx (0.48 °C and 0.45 °C per decade, respectively). In this case too, the A2 scenario predicts a more intense upward trend in TYn and TYx relative to RCP8.5, which was not to be expected given that RCP8.5 is a slightly more extreme variant than A2 SRES scenario.

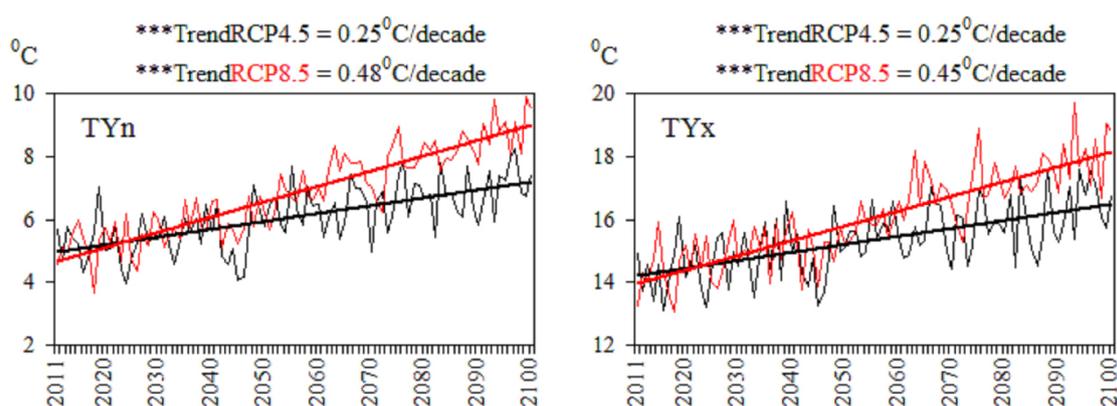


Fig. 5. Trend of projected average annual minimum (TYn) and maximum (TYx) temperatures in Kolašin, period 2011–2100, (Significance: ***p<0.001), RCP4.5 and RCP8.5 scenario CNRM-ALADIN53 model

The recorded absolute maximum temperature in Kolašin during the instrumentation period (1949–2019) is 37.1 °C and it was measured on August 23, 2012. According to A2 projections of the EBU-POM model scenario, the maximum temperature up to 43.8°C is possible by the end of the 21st century. The measured absolute minimum is –29.8 °C (registered January 13, 1985) and can be reduced to –32.1 °C by A2 scenario estimates. RCP scenarios give minor changes in temperature. According to RCP8.5, the projected absolute maximum temperature is 41.8°C and the absolute minimum is –19.1 °C (Table 7).

Table 7. Absolutely lowest and highest temperature in Kolašin registered and projected

T (°C)	Registered	Projections to 2100		
	(1949–2019)	A2	RCP4.5	RCP8.5
Abs. Tx	37.1	43.8	40.4	41.8
Abs. Tn	–29.8	–32.1	–16.5	–19.1

4. Discussion

Surveys for Montenegro, a spatially and population-small country belonging to the Mediterranean, show that in the second half of the 20th and the beginning of the 21st century, there was a significant trend of temperature increase (*Burić et al.*, 2018; 2019). The results of the temperature projection in Kolašin (northern part of Montenegro) presented in this paper indicate a warmer future.

The results for neighboring Serbia show that the period 2071–2100 will be warmer by 2 and 4°C for the A1B and A2 scenarios with respect to 1971–2000, respectively. It is likely that the number of TD will increase, while the total number of FD will decrease in the future. A shorter duration of the frost period and a longer duration of dry and vegetation periods over the Serbian region is expected (*Kržič et al.*, 2011).

Not only in Serbia, but throughout the Western Balkans, temperatures are expected to increase during the 21st century. *Djordjevic et al.* (2019) point out that at the end of the 21st century (2071–2100), the projected average annual temperature in the Western Balkans will be higher than 2 to 5.5 °C in relation to the 1971–2000 base period, depending on the selected scenario and part of the region. According to the NMMB model projections for the RCP8.5 scenario, the average increase in mean annual temperature over the period 2071–2100 is approximately 5.5 °C in most of the Western Balkans. Concerning precipitation, the results obtained by the aforementioned authors show that annual precipitation will have a negative tendency by the end of the 21st century in most of the Western Balkans, and in some areas the expected decrease may be up to –40% compared to the 1971 reference period –2000.

The uncertainty of climate models, both global (GCM) and RCM, has been considered in many papers (*Michaels et al.*, 2002; *Laprise et al.*, 2008; *Holtanová et al.*, 2010, 2014; *Kirtman et al.*, 2013; *Solman*, 2016; *Sanderson et al.*, 2017; *Belda et al.*, 2017; *Ongoma et al.*, 2018). *Holtanová et al.* (2019) point out that projections and interpretations of past and future climate change will be increasingly complicated, as there are significant differences in the results of both GCM and RCM between the two scenarios. When it comes to modeling, perhaps the best is *Box's* (1979) interpretation i.e., there is no exact model, but they are all useful.

In other words, modeling the climate future based on its current state is the only tool that indicates what can happen if we do not take care of the environment. That is why projections should be taken seriously. Modeling is improving day by day, different models and scenarios give different results. That is why our aim was to present the results of the latest climate simulations for the Western Balkans in this paper, using the example of temperature projections for the grid field to which Kolasin belongs (referring to RCP scenarios).

5. Conclusion

Montenegro is part of the Mediterranean and Southeastern Europe, that is, the Western Balkans, regions and subregions that are among the most vulnerable to climate change. This paper aimed to determine the magnitude and significance of the potential temperature change in Kolašin (north of Montenegro) according to projections of two models (EBU-POM and ALADIN), respectively, of three scenarios (A2, RCP4.5 and RCP8.5). All three scenarios give a significant increase in temperature by the end of the 21st century. Compared to the base period (1981–2010), projections indicate that the average annual temperature in 2071–2100 will be higher than +2.2 (RCP4.5) to + 3.6 °C (A2 and RCP8.5).

RCP8.5 is a slightly more extreme variant compared to the A2 SRES scenario. However, with the many temperature parameters considered for Kolašin, the A2 scenario predicts more intense changes than RCP8.5, which was not expected. For example, in 2071–2100, according to the A2 scenario, the annual average of SU and TD numbers will be +66.9 and +50.3 days higher than the base period, while RCP8.5 projects +45.4 and +23.2 days. This suggests that RCP scenarios are more reliable than SRES, which is logical because they have twice the resolution (better) than A2 (RCP = 12.5 km, A2 = 25 km).

In any case, the results of the study of several temperature parameters presented in this paper show that the Kolašin climate tends to become warmer with more frequent higher both maximum and minimum temperatures. These results can help decision makers take some mitigation and adaptation measures to potential climate change in the future, and generally environmental intervention. Montenegro is a small country and small economy, which has no impact on the global climate. But the slogan "work locally, think global" should be kept in mind. Therefore it is necessary to reduce the use of fossil fuels and switch to clean energy sources. As a Mediterranean country, Montenegro has significant potential for the use of solar energy.

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