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INDEXES OF TEMPERATURE AND PRECIPITATION EXTREMES IN PODGORICA IN THE PERIOD 1951 – 2008

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Abstract: World Meteorological Organisation has defined a series of indices and proposed using of them in research of climate changes, in analysis of air temperature extremes changes, quantities of precipitation and other meteorological parameters. In large part of the Montenegro, annual values of air temerature and quantity of precipitation show statistically significant trend, or slight aridisation in the second half of the XX and by the beginning of the XXI century. In Podgorica, in the period from 1951 to 2008 trend of average annual temperature and annual precipitation sums is 0.155°C (1.0%), or -4.2 mm (-0.3%) per decade. The aim of this research was to determine on the basis of complex analysis of daily extremes indices what causes, in mathematical terms, growth of average annual temperature and decrease of annual quantities of precipitation on the sample of data for Podgorica, in the period 1951 – 2008. Acquired results indicate that the perceived tendency of warming in Podgorica is, first of all, a consequence of more often appearance of maximal and minimal daily temperatures which have warmer values. On the other hand, in mathemathical terms, statistically important increase of frequency of drought days and slight decrease of humid days give contribution to decrease, statistically insignificant, of annual amounts of precipitation in the period of 58 years.

Key words: air temperature, precipitation, indices, trend, Podgorica.

Introduction

In the reports of World Meteorological Organization, Intergovernmental Panel on Climate Change (WMO, IPCC) and some expert works, it is emphasized that in the conditions of antropogenic warming, the growth of intensity and frequency of temperature, precipitation and other extreme weather events should be expected in the future. For that reason, the expert team for detection and monitoring of climate changes of the World Meteorological Organisation (Commission for climatology – WMO-CCL) and World Climate Research Programme (CLIVAR), proposed a series of meteorological parameters indices (Gajić-Čapka, 2009; Groisman et al., 2005; WMO, 2001, 2004). The proposed climate changes indices are related to the days when the temperature or

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precipitation exceed certain rates defined according to the standards of WMO-CCL and CLIVAR.

The researches show that in the period from 1951 to 2008, a great number of meteorological stations in Montenegro recorded trend of growth of the average annual air temperature and drop of the annual precipitation amounts (Burić, Ducić, & Luković, in press). The aim of this work is to determine on the basis of the data from Podgorica what causes in mathematical terms growth of average annual temperature and decrease of annual quantities of precipitation in the period from 1951 to 2008. Podgorica is the capital city with the biggest population in Montenegro. It is the main economic and cultural centre. (Figure 1).

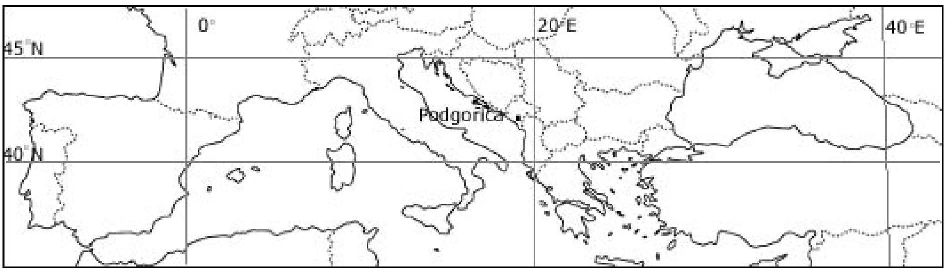

Figure 1. Location map of Podgorica, Montenegro

Working asumption is that in Podgorica, in the period from 1951 to 2008, statistically significant warming and insignificant aridisation occurred due to the changes in frequency of characteristic days with air temperature and precipitation amounts above or under the defined limits. Hence, the answer to the asked question was given in the complex analysis of daily extremes indices of those two most important climate elements.

Database and research methodology

The data of the Meteorological station in Podgorica were used for the analysis of changes of temperature and precipitation extremes since it is the main meteorological station. The series was complete, and through testing and checking of the data, it was confirmed that the measurings were correct (CLIDATA database of the Meteorological and Hydrologycal Service was used). The indices of the extreme values of air temperature and precipitation amounts were calculated based on the daily data for the period from 1951 to 2008.

From the list of climate changes indices, for the purpose of the analysis of the temperature extremes, six (three warm and three cold) temperature indices were determined. Four indices were defined by the means of percentile (10th and 90th percentile of maximal (Tx) or minimal (Tn) values of daily air temperatures of the standard climate period from 1961 to 1990), and two are related to the number of frosty and summer days (indices defined by fixed rates - daily $Tn < 0^{\circ}C$ and $Tx > 25^{\circ}C$).

For the analysis of precipitation extremes, five indices were selected (four humid and one dry). Three precipitation indices (DD, R75% and R95%) are related to frequency and they are defined as the number of days in which daily amount of precipitation (Rd) does not exeed fixed rate of 1 mm (dry days), or it exeeds changable rates of Rd > 75th percentile (humid days) and Rd > 95th percentile (very humid days). Percentile rates are defined from the sample of all precipitation days in which the height of water sediment at least 1 mm (Rd ≥ 1.0 mm) in the climate period from 1961 to 1990. The next two indices (DI and R95%T) are related to the intensity of precipitations. The DI index shows the average height of precipitation per precipitation day when at least 1 mm precipitates, and it is the first indicator about the average precipitation intensity. The index R95%T shows the average precipitation intensity in a very rainy (wet) day. This index is selected in order to examine if there is either growth or decrease of great daily amounts of precipitation which can cause floods, soil erosions and other disasters that occured in 2010 (floods in January and December at Scadar Lake coast, Bojana, Zeta and the other rivers). Abbreviations and definitions of the used indices are given in the Table 1.

Essencially, the temperature and the precipitation indices are characteristic days, defined by WMO-CCL/CLIVAR, which has recently been used in research of the changes of the extremes incurred due to the climate changes. Calculating of the tendency of the absolute temperature and precipitation extremes is not practised in the analysis of the climate variations, especially at the annual level since those are rare occurances. The importance of the climate indices which are determined by the means of percentile rates is in the fact that they provide spatial comparison since they are defined according to the same empirical allocation of the extremes and they take in consideration some more temperate extremes (10th and 90th percentile for the temperature, or 75th and 95th for the precipitation), but with clear consequences (Gajić-Čapka, 2009; Vinset & Mekis, 2005). For the same reason, the precipitation intensity indices are given in the percentage of deviations from the climate standard period 1961 – 1990.

Table 1. Indices of the temperature and the precipitation extremes

No.	Index	Unit	Definition
			Cold temperature indices
1.	FD	No. of days	Number of frosty days in the unit of time (daily Tn<0°C).
2.	Tx10%	No. of days	Number of cold days (daily Tx < 10th percentile of the reference period 1961-1990).
3.	Tn10%	No. of days	Number of cold nights (daily Tn < 10th percentile of the reference period 1961-1990).
			Warm temperature indices
1.	SU	No. of days	Number of summer days in the unit of time (daily Tx>25°C).
2.	Tx90%	No. of days	Number of warm days (daily Tx > 90th percentile of the reference period 1961-1990).
3.	Tn90%	No. of days	Number of warm nights (daily Tn > 90th percentile of the reference period 1961-1990).
			Precipitation extremes indices
1.	DD	No. of days	Number of dry days in the time unit (daily amount of precipitation Rd < 1 mm).
2.	DI	%	Average daily precipitation intensity per precipitation day (ratio of the total precipitation amount and the total number of precipitation days for Rd ≥ 1 mm).
3.	R75%	No. of days	Number of moderately wet days (Rd > 75th percentile of the daily allocation for days Rd ≥ 1mm of the period 1961-1990).
4.	R95%	No. of days	Number of very wet days (Rd > 95th percentile of the daily allocation for days Rd ≥ 1mm of the period 1961-1990).
5.	R95%T	%	Average daily precipitation intensity in a very wet day (ratio of the total precipitation amount and the total number of precipitation days for Rd > 95th percentile).

Source: (Klein Tank & Konnen, 2003). Abbreviations and definitions are given based on standardisation of WMO-CCL/CLIVAR Working Group for determining of climate changes

Common mathematical – statistical methods – line trend, percentile method, sliding averages, standardized deviations, etc. were used in the work. The trend was calculated by the method of least squares, and statistical importance was defined on the basis of the total number of elements of the series minus 2 (n-2 degrees of option) and determination coefficient (R^2), that is by Student's test.

Results and disscusion

In the period 1951 – 2008, warm temperature indices show growth tendency in Podgorica. The most outstanding trend was perceived at summer days (SU), whose number increased by rate of 3.6 days per decade. Warm days show slightly smaller degree of growth per line trend - (Tx90%), 3.5 days per decade. During the observed period, the number of warm nights increased (Tn90%), 2.5 days per decade. It is important to emphasize that the perceived changes (growth) per trendline, are statistically significant for all categories of warm days (Figure 2, left). The cold days (Tx10%), out of the cold indices; show statistically important negative trend, whose number decreased by the average intensity of 2.5 days per decade. The annual number of frosty days and cold nights (FD i Tn10%) do not practically show any trend (0.0 days per ten years) in the period from 1951 to 2008. (Figure 2, right).

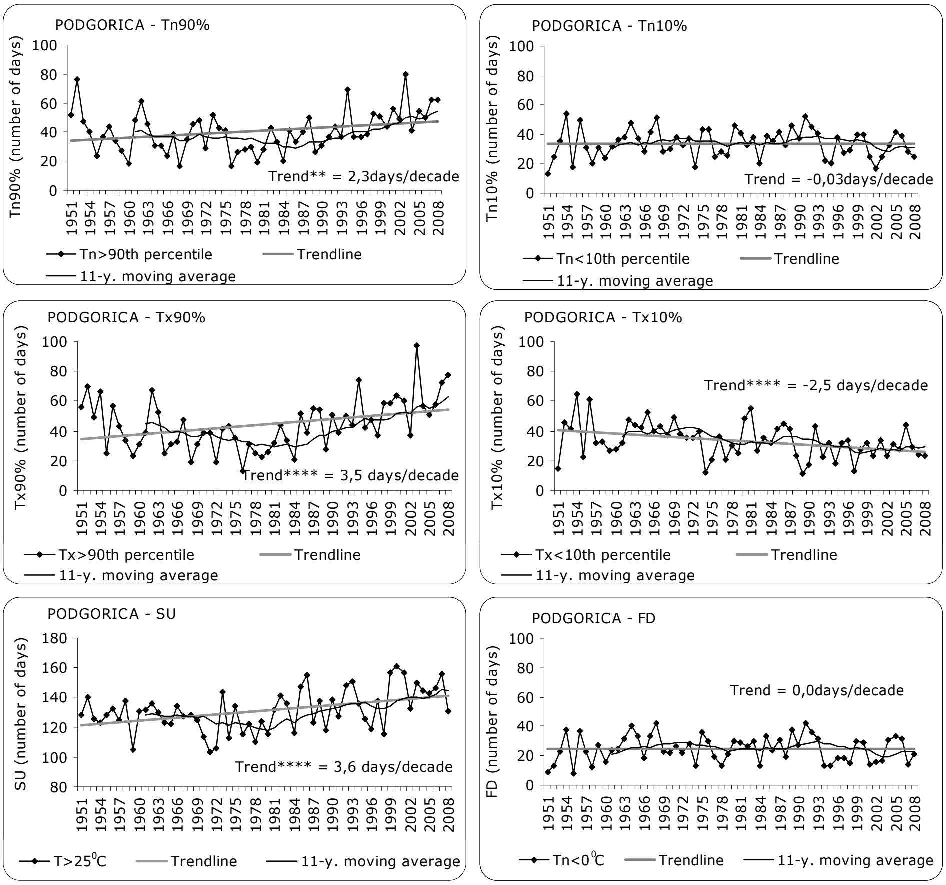

Figure 2. The trend of warm (left) and cold (right) temperature indices in Podgorica for the period 1951 – 2008. – Number of days and suitable 11 years sliding averages; (**** (**) – significant at the level α=0.01 (0.05))

Therefore, analysis of the daily temperature extremes according to the very strict criteria, in the period 1951 – 2008, shows that in Podgorica there are more often maximal and minimal daily temperatures which have “warmer” values. By other words, the analysis confirmed the working assumption that warming perceived in average temperatures at annual level, is a consequence of the increase of frequency of the daily temperature extremes in positive sense. The changes in the trend of the warm temperature indices are grater than the changes of the cold indices which is in accordance with the fact that there has been higher level of increase of the warm than there has been decrease level of the cold days, generally.

In the report of the Intergovernmental Panel on Climate Change (IPCC), it is emphasized that due to the anthropogenic warming of the Earth, frequency and intensity of the certain types of weather extremes have been increased and further increase (amplification) should be expected in future (IPCC, 2001a, 2001b, 2007a, 2007b). As far as the temperature is concerned, it should be expected that maximal values will be higher and minimal ones will be lower. The analysis of the daily maximal temperatures is in accordance with the previous, while it cannot be said for the mimimal values. However, the days with the maximal and minimal temperatures between the 10th and the 90th percentile of the normal allocation in a year (scope of the common values - average days) has the absolute domination. The number of the average days with maximal temperatures in the mentioned scope (10 – 90th percentile) shows statistically insignificant tendency of decrease in the period from 1951 to 2008, while the negative trend with the common minimal temperatures is a little higher, which is consistent with the previous conclusions. At the end of examination of the temperature indices, it is necessary to stress that perceived warming in Podgorica, in the observed 58 year period, is partially ascribed to the influence of the urban island of heat (Burić et al., in press).

The tendency of frequency and intensity of the precipitation extremes is also a good indicator of the precipitation circumstances change. In the area of Podgorica, there is statistically important growth of the annual number of dry days (DD). The number of these days was increasing in the observed 58 year period for average 2.9 days per decade (Figure 3). It means, in other words, that in the second half of the 20th and by the beginning of the 21st century, there was the tendency of decrease of the precipitation days, also per rate of 2.9 days per ten years. Otherwise, raininess expressed in the precipitation days in which there is at least 1 mm of precipitation, shows that Podgorica has average 101 precipitation day per year, or approximately 28% of days in a year. This is the first indicator, strictly mathematically observed, of explanation of insignificant decrease tendency of the annual amounts in the observed 58 year period, but not sufficient one. Therefore, precipitation days are rarer and the question is: In what direction do the daily precipitation amounts change, or what happens with the tendency of the daily precipitation intensity?

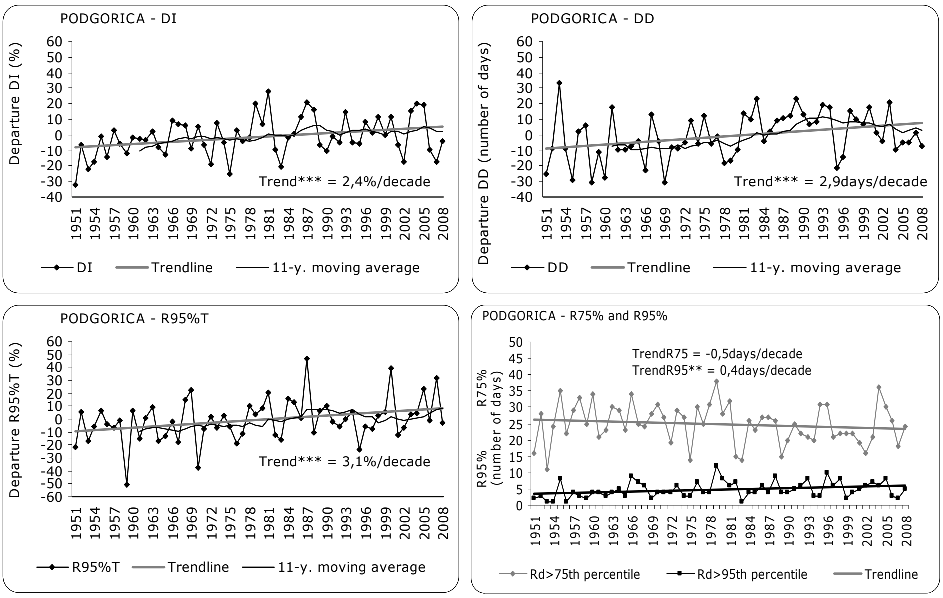

Figure 3. Time series of the precipitation extremes indices, 11 year sliding averages and the trends in Podgorica (significant at the level: ** - 95%; *** - 98%), for the period 1951 – 2008.

More detailed picture of the daily precipitation circumstances in the area of Podgorica is given by the average daily precipitation intensity per precipitation day (DI). This index has a positive trend, statistically significant. The analysis of the trend shows that the daily precipitation amounts increased in the precipitation days for rate of 2.4% per decade in the observed 58 year period. The amount of precipitation per precipitation day has growing tendency and the next question is: Is there growth of great amounts which may have unwished effects? By other words, it is needed to see in what degree the determined decrease of the annual amounts, the decrease of the number of the precipitation days and the daily intensity increase can be ascribed to the change of the number of the wet and the very wet days. For that reason, the daily precipitation amounts greater than 75th and 95th percentiles were analysed. In the Table 2, there are results of the temperature and the precipitation extremes trend, or of the number of characteristic days and precipitation intensity, as well as the significance of the changes.

Table 2. The temperature and the precipitation extremes trend and the significance of the changes in Podgorica for the period 1951 – 2008

Index	Rate	Trend	Significance
		Cold Temperature Indices	
FD	Tn < 0°C	0,0 day/decade	No
Tx10%	Tx < 9.4°C	-2.5 days/ decade	Yes (0.01)
Tn10%	Tn < 0.8°C	0.0 day/decade	No
		Warm Temperature Indices	
SU	Tx > 25°C	+3.6 days/decade	Yes (0.01)
Tx90%	Tx > 32.2°C	+3.5 days/decade	Yes (0.01)
Tn90%	Tn > 20.5°C	+2.3 days/decade	Yes (0.05)
		Precipitation Extremes Indices	
DD	Rd < 1 mm	+2.9 days/decade	Yes (0.02)
DI	///	+2.4%/decade	Yes (0.02)
R75%	Rd > 22.2 mm	-0,5 days/decade	No
R95%	Rd > 53.0mm	+0,4 days/decade	Yes (0.05)
R95%T	///	+3,1%/decade	Yes (0.02)
R95%ΣR	///	+2,5%/decade	Yes (0.01)

In the period 1951 – 2008, in Podgorica, there was statistically insignificant decrease of the wet days (R75%), and the average annual number of the wet days is 25. On the other hand, frequency of the number of the very rainy (wet) days shows a tendency of growth, 0.5 day /10years, significant at the 5% level of the risk of acceptance of the hyphothesis. In the average year, Podgorica has only about five very rainy days, which is why the growth of 0.5 day per decade is statistically significant. The index R95%T should show in what degree the determined changes can be ascribed to the change of precipitation amounts that occur during the very wet days. This index has a positive trend, which means that there is a growth of the great daily amounts, statistically significant at 98% level of trust. Namely, the precipition intensity during the very wet days shows a tendency of growth per rate of 3.1% for 10 years.

The analysis includes one percipitation index more, R95%ΣR which shows participation of the great daily precipitation amounts (R95%) in the total annual amount (ΣR). By the method of least squares, it was determined that this index had a positive trend 2.5% for 10 years. This means that the participation of the great daily amounts is increasing in the total annual amount.

Conclusion

In the work, the mathemathical reasons for the statistically significant increase of the average air temperature and insignificant decrease of the annual precipitation quantities in Podgorica, in the period from 1951 to 2008 have been researched. The acquired results show that the tendency of increase of the average annual temperature is, strictly mathematically, a consequence of, first of all, positive values of the warm temperature indices trend. Namely, in the period from 1951 to 2008, in Podgorica, there are more maximal and minimal daily temperatures which have "warmer" values. In mathemathical terms, statistically significant increase of the frequency of the dry days and slight decrease of the wet days give contribution to the statistically insignificant decrease of the annual precipitation amounts in 58 years period. On the other hand, the precipitation intensity in a precipitation and very wet day, as well as the frequency of the very wet days and participation of great daily amounts of precipitation show statistically very significant growth tendency. Simply, there is a signal of the changes related to the great daily amounts and frequency of the very wet days, but in the annual sum it is almost eliminated by the decrease of the number of the precipitation and wet days and then the annual amounts do not show changes by the line trend.

The researches show that in the last two decades, the annual amounts of the precipitation have had a growth tendency in Podgorica and in the other parts of Montenegro. As far as the temperature is concerned, almost all measuring places show that the last observed decade (1999 – 2008), in the average value, is the warmest one in the instrumental period, from 1949. However a greater number of stations register insignificant tendency of growth and several of them register even a trend of decrease of the average annual temperature in the decade 1999 – 2008. (Burić et al., in press). This contradiction is of methodological nature. The above mentioned and the facts that over this area, air masses of different features are mixed and met (baric deformation field – area of discontinuity) and Montenegro has a very diversified and dissected relief (Burić, Ivanović, & Mitrović, 2007), indicate that it is necessary to do further researches or analyses of the extremes indices on the other laocations in order to check if the changes are in accordance with the results for Podgorica.

Since certain changes of air temperature and precipitation are detected, which is proved in this work based on the example of data for Podgorica, it is also needed to try to answer to the very actual question: what is a cause of those changes? Furthermore, besides the research of possible influence of anthropogenic causees of greenhouse effects, it is necessary to do the research of external and internal climate factors that are always present. In this respect, by researching of possible impact of the anthropogenic effect of the greenhouse and several external and internal natural factors (volcanic eruptions, change of the Sun's activity, El Ninjo's effect, North-Atlantic oscillations, Atlantic longtime oscillations, Arctic oscillations) on variation of climate in Montenegro, Burić et al. (in press) concluded: "Having in mind the acquired results of our research as well as the results of some other authors, we think that it is wrong to accent exclusive and persistent domination of one factor , since it is obvious that there is an interactive function of more effects".

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