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RELATIONSHIP BETWEEN MEAN ANNUAL TEMPERATURES AND PRECIPITATION SUMS IN MONTENEGRO BETWEEN 1951-1980 AND 1981-2010 PERIODS

Abstract: In the second half of the 20th and by the beginning of the 21st century the area of Montenegro was dominated by positive air temperature fluctuations and negative precipitation sums. This paper analyses a 60-year period (1951-2010), with the aim to determine air temperature and precipitation deviation between the two 30-year periods: 1951-1980 and 1981-2010. Calculations of mean, mean maximum and mean minimum temperature have been done, as well as annual values of precipitation sums. All three temperature parameters, particularly maximum values, show that the 1981-2010 period was significantly warmer in relation to previous three decades. Significant changes in mean annual precipitation sums between the two observation periods have been recorded on the coast and, locally, in the western part of the country. The results also showed that there was a significant increase in positive deviations of mean maximum temperature in most parts of Montenegro during the 1981-2010 period in relation to the 1951-1980 period, while changes of this type in other observation parameters were mostly minor.

Key words: temperature, precipitation, Montenegro

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Introduction

According to the data of the World Meteorological Organization (WMO), a long term trend of global temperature growth is continuing (WMO, 2011; WMO, 2012). In the statement issued by WMO[2] it is said that the decade of 2001-2010 was, on the global level, the warmest one in the instrumental period, with an emphasis on the "rate of global temperature growth during the previous four decades (1971-2010), which was, according to preliminary data, almost three times higher in relation to the previous 130-year period". 48 (47%) countries out of 102 registered absolute maximum temperature in this decade (2001-2010), 20% of the countries did it in the period of 1991-2000, and other countries in previous decades (Fig. 1, right columns) (Press Release No. 943).

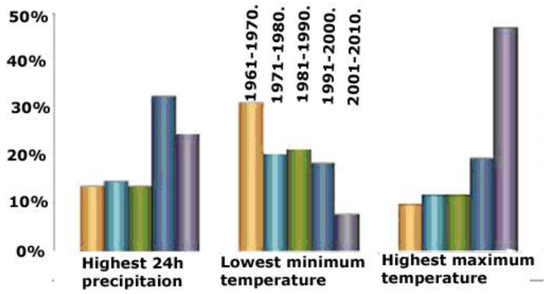

Fig.1. Percentage occurrence of extreme events in 102 countries of the world in the decades during the 1961-2010 period - highest 24-hour precipitation sums (left columns), lowest minimum temperature (middle columns) and highest maximum temperature (right columns) (Source: http://www.wmo.int/pages/mediacentre/press_releases/pr_943_en.html)

Since 1979, the region of Europe has experienced relatively rapid warming trend, both on seasonal and annual levels. Autumn season is an exception with a trend of a slight temperature decrease (Klein-Tank & Konnen, 2003; Della-Marta et al., 2007). Regionally, South Europe is warming fastest, while Atlantic coast is warming least (Del Río et al., 2005).

As for the Mediterranean, there are certain contrasts. Thus, Del Río et al. (2011) have found that Spain evidenced the most significant increasing trend in spring and summer temperatures during the period 1961-2006. On the opposite side of the region, in Turkey, Türkeş et al. (2002) identified a significant increasing trend of annual, winter and spring temperatures on the south of the country during the period 1929-1999, while there was a tendency of temperature decrease in the northern and central parts during the summer and autumn seasons. In Greece, Feidas et al. (2004) have found a negative trend of winter temperature for the period 1955-2001. Results for Italy (Brunetti et al., 2006) show a warming trend over the whole area during the instrumental period, but the second half of the 20th century records a more significant increase in maximum than minimum temperature, while the whole period shows the opposite.

Burić et al. (2014; 2015) estimated the trend of a few air temperature parameters in the area of Montenegro. A detailed analysis for the 1951-2010 period shows the most distinct increasing trend of mean summer temperature, which is statistically significant

[2] http://www.wmo.int/pages/mediacentre/press_releases/pr_943_en.html

in almost all locations. Considered as a whole (for the whole area of Montenegro), the trend of mean summer temperature is 0.23°C/per decade. A slightly smaller increase of mean spring temperature has been recorded (0.17°C/per decade), but it is also significant on a large number of stations. There is also a significant temperature increase on annual level (0.11°C/per decade).

The statement issued by WMO in 2012 (Press Release No. 943)[3] says that the global precipitation sums in the 2001-2010 decade are the second largest in the series from 1901 (the first is the 1951-1960 decade), with an emphasis on big regional and interannual differences observed during the period. Generally, a conclusion can be made that the precipitation sums decreased in the region of Mediterranean in the second half of the 20th century, but the changes are mainly insignificant (Reiser & Kutiel, 2010). Yet, Xoplaki et al. (2006) claimed a significant decrease in winter precipitation sums in most parts of Italy, Albania, Croatia, Cypress, on the west of Greece, as well as in Israel and Romania, while there was an insignificant increasing trend in Libya, Egypt, Tunisia and along the Mediterranean coast of Spain. Feidas et al. (2007) point to the fact that the annual precipitation sums significantly decreased in the area of Greece in the period 1955-2001, with the exception of the southern area where the changes were insignificant. Del Río et al. (2011) claimed that there was also a negative precipitation trend on the Iberian Peninsula during the 1961-2006 period.

During the 60-year period (1951-2010) no significant changes in the trend of annual precipitation sums were observed in most parts of Montenegro. No increase in the drought intensity was recorded in most areas of the country, except partly on the coast region and in the western parts. Moreover, the period 1981-2010 was marked by moisture increase in almost whole country, which definitely means that expected aridity tendencies of the area can't be discussed. During this period (1981-2010), the trend of annual precipitation sums was negative only on one meteorological station (Plav), while it was positive on all other stations, with the values ranging from 20.8 mm per decade in Berane, to even 880 mm/ per decade in Crkvice (Бурић, 2014).

Considering everything stated above, this paper had the following objective. Firstly, to estimate mean values and dispersions (deviations) of examined air temperature and precipitation sum parameters for the two same length time series. Secondly, a thorough inquiry into statistical significance of the difference between mean values and deviations of temperature and precipitation sums between the two 30-year periods: 1951-1980 and 1981-2010. Calculations have been done for mean, mean maximum and mean minimum temperature, as well as for the precipitation sums on annual level.

Data and methodology

Temperature and precipitation sums data taken from 23 meteorological stations (Fig. 1) for the 1951-2010 period have been used in this research. The investigation into series homogeneity and filling in of missing data has been done by MASH v 3.02 and MISH v 1.02. These two software packages for extrapolation and investigation into series homogeneity of meteorological data have been developed by Hungarian Weather Service.

[3] http://www.wmo.int/pages/mediacentre/press_releases/pr_943_en.html

Original versions (Szentimrey, 2003; Szentimrey & Bihari, 2007) of both software packages have been modified, and the final versions were presented by the authors within the training called "Application of climatological methods for interpolation and homogenization", which was held from February 2, to February 5, 2010 in Budapest. Having tested a few methods for these purposes, and for the purpose of uniformity, World Meteorological Organization (WMO) recommended the use of MASH v 3.02 and MISH v 1.02, particularly when daily data are considered. These methods use Kriging algorithms for interpolation and, based on the data taken from all stations in the vicinity, an estimation of a corresponding daily value is done in grids of 100 x 100 m.

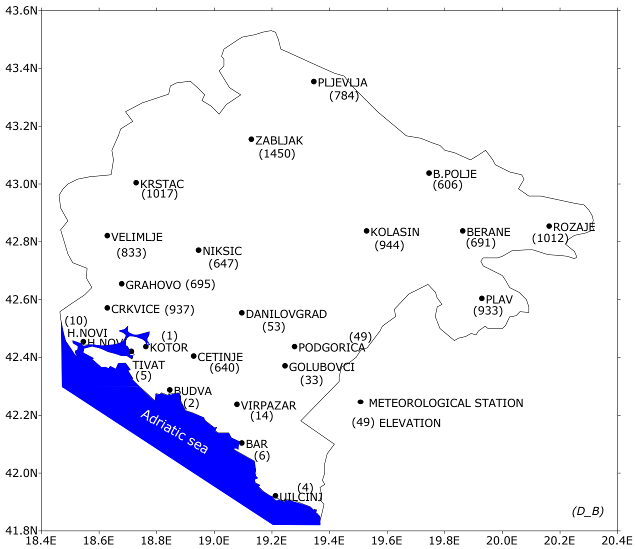

Fig. 2. Locations and altitudes of meteorological stations included in the analysis

Statistical significance of difference between mean annual values of temperature and precipitations sums for the 1951-1980 and 1981-2010 periods has been checked by t-test. Therefore, null hypothesis will be tested (H_0 – mean values of the two analyzed periods are equal: $\bar{x}_1 = \bar{x}_2$) with an alternative hypothesis (H_1, $\bar{x}_1 \neq \bar{x}_2$). For the series of 30 or more data values ($n \geq 30$), an approximative method standardized with normal distribution will be used for investigation into statistical significance (t) of their mean values, that is, the formula (Вукадиновић, 1981):

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\delta \cdot (\bar{x}_1 - \bar{x}_2)}$$

Denominator in the formula is derived from:

$$\delta \cdot (\bar{x}_1 - \bar{x}_2) = \sqrt{\frac{Sd_1^{\ 2}}{n_1} + \frac{Sd_2^{\ 2}}{n_2}}$$

$\bar{x}_1$ ($\bar{x}_2$) – mean value of the first (second) series;
Sd_1 (Sd_2) – standard deviation of the first (second) series;
n_1 (n_2) – number of data values of the first (second) series;

Critical values for t are shown in the table for different probability levels (t_α). Tabular value t_α for the 0.05 and 0.01 probability is most often used as a limit for acceptance or rejection of the zero hypothesis. The hypothesis is accepted with the significance threshold α if the value t calculated by the formula belongs to the interval ±α: t є ± α. On the other hand, if the value t calculated by the formula is bigger than the tabular (t_α) for the 0.05 (or 0.01) probability, then the zero hypothesis is rejected, that is, the difference between the two mean values is statistically significant.

Deviations of some individual data values in the series, in relation to the corresponding mean values, can point to the stability of synoptic conditions, accuracy of the instruments, etc. There lies the greatest importance of deviations, which serve as an index of the dispersion of data around the average. The testing has been carried out by Fisher's distribution (F-test), with the risk of 0.05 and 0.01, that is, with the confidence level of 0.95 and 0.99, by the formula (Ивковић, 1976):

$$F = \frac{n_1 \cdot Sd_1^2 (n_2 - 1)}{n_2 \cdot Sd_2^2 (n_1 - 1)} \approx \frac{Sd_1^2}{Sd_2^2}$$

Terms of the equation are the same as in previous formula, bearing in mind that F values should be calculated in the way to make numerator in the formula bigger, so that way F is always bigger than 1. If the value derived by the formula is bigger than the theoretical one, which is given in the Fisher distribution table, for a degree of freedom n_2-1 and n_1-1 and a certain significance threshold, then the hypothesis of equality of variances ($\sigma_1^2=\sigma_2^2$ or $Sd_1^2=Sd_2^2$) is rejected, that is, the deviation is considered to be significant ($F>F_\alpha$), or vice versa.

Results and discussion

Statistical significance of the difference between the temperature and precipitation in two periods

Based on obtained data, it can be concluded that on 16 stations the second half of the observation period (1981-2010) was significantly warmer than the first one (1951-1980). In other words, it means the rejection of the hypothesis H_0 with the risk of 5% in Velimlje, that is, of 1% on other 15 stations, since the temperature increase in the period 1981-2010 is significant on the confidence level of 95% and 99%. The highest increase in mean annual temperature has been recorded in Berane, Plav (0.7°C), Podgorica and Zabljak (0.6°C).

Calculations have been done both for mean annual, maximum (T_{xsr}) and mean minimum (T_{nsr}) temperature, for each station separately. Mean annual maximum temperature on all stations is higher in the second half of the 30-year period (1981-2010) than in the first one (1951-1980). In addition to that, the difference in mean maximum temperature between the two observation periods is significant on the risk probability level of 1% considering the acceptance of the hypothesis (99% confidence level), including all the stations. On the basis of these parameters, warming is most pronounced in Podgorica, Berane, and on Zabljak (1.1°C), while the lowest increase in mean annual maximum temperature was recorded in Herceg Novi (0.4°C).

Considering mean annual minimum temperature, the second half of the observation period is significantly warmer than the first one on 12 stations. The increase of mean annual minimum temperature in Kolasin (0.3°C) and Budva (0.4°C), according to Student's test, satisfies the significance requirements on 95%, while on other 10 stations the confidence level is 99%. The highest increase in minimum temperature is recorded in the northern and northeastern areas of the country: Rozaje (1.2°C), Berane (0.9°C), Bijelo Polje, Zabljak, Pljevlja, as well as the Bar station (0.7°C).

Previous analysis showed that the mean annual maximum temperature had significantly changed on all observation stations during the second 30-year period, compared to the values from the 1951-1980 period. In most parts of Montenegro there were significant changes in both mean minimum temperature and its extremes. Thus, considering the annual values, all three temperature parameters, maximum values in particular, show that the 1981-2010 period was significantly warmer in relation to previous three decades.

Tab. 1. Statistical significance of the difference in the mean (T_{sr}), mean maximum (T_{xsr}), mean minimum (T_{nsr}) annual temperature and annual precipitation sums (RR) between 1951-1980 ($\bar{X}_1$) and 1981-2010 ($\bar{X}_2$) periods

Stations	T_{sr}	T_{xsr}	T_{nsr}	RR
	$\bar{X}_2-\bar{X}_1$	$\bar{X}_2-\bar{X}_1$	$\bar{X}_2-\bar{X}_1$	$\bar{X}_2-\bar{X}_1$
Ulcinj	0.5**	0.6**	0.6**	-147.5*
Bar	0.5**	0.7**	0.7**	-143.2*
Budva	0.5**	0.7**	0.4*	-220.8*
Tivat	-0.1	0.6**	0.1	-202.3*
Kotor	0.3**	0.6**	0.1	-198.0*
Herceg Novi	0.3**	0.4**	0.6**	-241.4*
Virpazar	-0.1	0.9**	0.1	-221.9
Golubovci	0.5**	0.9**	0.1	-66.3
Podgorica	0.6**	1.1**	0.3	-64.2
Danilovgrad	0.1	0.9**	0.5**	-67.0
Cetinje	0.1	1.0**	-0.1	-20.5
Crkvice	0.1	0.9**	-0.2	-555.1
Grahovo	-0.1	0.8**	-0.1	-189.4
Velimlje	0.4*	0.8**	0.1	-139.1
Niksic	0.4**	0.8**	0.2	-130.3
Krstac	0.1	0.8**	0.1	-361.5**
Kolasin	0.4**	0.5**	0.3*	8.5
Plav	0.7**	0.6**	0.7**	-69.2
Rozaje	0.6**	0.6**	1.2**	37.9
Berane	0.7**	1.1**	0.9**	-34.6
Bijelo Polje	0.5**	0.5**	0.7**	26.0
Zabljak	0.6**	1.1**	0.7**	-41.9
Pljevlja	0.5**	0.8**	0.7**	-24.2

Significance of the difference on the risk level: ** $\alpha = 0.01$ and * $\alpha = 0.05$.

▪Some difference values do not coincide because of the reduction to one decimal

The greater part of Montenegro (20 stations) recorded a reduction in precipitation in the period 1981-2010 in relation to the 1951-1980 period. In Kolasin, Rozaje and Bijelo Polje the annual average of precipitation is insignificantly higher in the second than in the first 30-year period. Smaller average annual precipitation sum in the second (1981-2010) period, compared to the first one (1951-1980), is statistically significant only on 7 stations (Ulcinj, Bar, Budva, Tivat, Kotor, Herceg Novi and Krstac). In other words, it means that there are significant changes in mean annual precipitation sums between the two observation periods on the coastal region, with the 95% accuracy confidence of the hypothesis, and locally, in the western part of the country (Krstac), on the 99% confidence level.

Looking at the changes in annual precipitation sums this way, that is, as the difference between the two 30-year periods, a conclusion can be drawn that there was a slight aridization, except on the far northeast of the country, but this decrease in precipitation is insignificant in most parts of Montenegro (Tab. 1). Yet, it should be noted that annual precipitation trend is positive in almost the whole area of Montenegro (Бурић, 2014).

Statistical significance of the dispersion difference between the two periods

Estimate results for observed air temperature parameters show an increase in dispersion during the 1981-2010 period in most parts of Montenegro compared to the previous 30-year period (1951-1980). However, the dispersion (variance) increase of mean annual temperature in the second half of the observation period is significant only in Bar and Budva (2.7 and 2.3 times). There is also a statistical significance in Virpazar, but this station recorded 2.2 times bigger variance in the first than in the second 30-year period. On other stations, the difference in variances of mean annual temperature between the two observation periods is insignificant.

Apart from Cetinje, the ratio of variances of mean annual maximum temperature is higher than 1 on all other stations, which means that there was an increase in dispersion in the second 30-year period (1981-2010). Based on n_2-1 and n_1-1 degrees of freedom, corresponding values of variances and the length of time series, it has been proved that the dispersion increase in mean annual maximum temperature in the second 30-year period satisfies the F-test requirements on 13 stations, at the level of 99% on 5 stations, and at 95% confidence level on 8 stations. This means that there was a significant variance increase (Tab. 2) in most parts of Montenegro and, therefore, null hypothesis (H_0, $Sd_1^2=Sd_2^2$) is rejected.

Considering mean annual minimum temperature, dispersion difference between the two observed periods is insignificant on 20 stations. Dispersion increase in Bar and Rozaje during the second 30-year period, which was 2.8 and 2.5 times bigger than during the first period, is significant at 99% and 95% confidence level. F-test requirements are also satisfied by the results for Grahovo, at 95% level, but the dispersion (fluctuation) was 2.2 times bigger in the first period.

Variance values between the two 30-year periods are different on almost all stations, which is not unusual at all. The main question is: does this difference satisfy requirements of significance? As for mean annual and mean annual minimum temperature, variances of the observation periods are insignificantly different in most parts of Montenegro, that is, on 20 out of 23 stations. The results show that variances of average annual precipitation sums during the two observation periods are also insignificantly different. A significant difference in precipitation variances was recorded only in Berane (95% confidence level), but the dispersion was 2.0 times bigger in the first than in the second 30-year period. The biggest and significant dispersion increase on 13 stations during the period 1981-2010 compared to the 1951-1980 period was recorded for mean annual maximum temperature.

Tab. 2. Statistical significance of the dispersion change in mean annual (T_{sr}), mean maximum (T_{xsr}) and mean minimum (T_{nsr}) temperature, that is, average annual precipitation sums in 1951-1980 (Sd_1^2) and 1981-2010 (Sd_2^2) periods

Meteorological stations	T_{sr} Sd_2^2/Sd_1^2	T_{xsr} Sd_2^2/Sd_1^2	T_{nsr} Sd_2^2/Sd_1^2	RR Sd_2^2/Sd_1^2
Ulcinj	1.1	2.0*	1.5	1.5
Bar	2.7**	3.7**	2.8**	1.3
Budva	2.3*	4.2**	1.5	1.7
Tivat	1.2	3.2**	0.8 (1.3)	1.5
Kotor	1.3	2.2*	1.0	1.4
Herceg Novi	1.2	3.9**	1.0	1.3
Virpazar	0.5(2.2)*	3.0**	1.5	1.2
Golubovci	1.6	2.5*	1.8	1.1
Podgorica	1.4	2.4*	1.4	0.9 (1.1)
Danilovgrad	0.6(1.7)	1.4	0.6 (1.5)	0.7 (1.4)
Cetinje	0.5(1.8)	1.0	0.9 (1.1)	1.4
Crkvice	1.0	1.8	1.3	1.8
Grahovo	0.8(1.2)	2.2*	0.4 (2.2)*	1.5
Velimlje	1.4	1.8	0.9 (1.1)	1.3
Niksic	1.4	1.1	1.5	1.0
Krstac	1.8	3.5**	0.6 (1.6)	0.8 (1.3)
Kolasin	1.6	1.6	1.1	0.7 (1.5)
Plav	1.7	1.5	2.0	1.7
Rozaje	1.7	1.6	2.5*	0.9 (1.1)
Berane	1.2	1.6	0.8 (1.3)	0.5 (2.0)*
Bijelo Polje	1.8	2.1*	1.0	1.2
Zabljak	1.7	2.6*	1.2	0.7 (1.5)
Pljevlja	1.1	1.6	0.9 (1.2)	1.0

Significance of dispersion change at the risk level: ** $\alpha = 0.01$ and * $\alpha = 0.05$.
Some values do not coincide because of the reduction to one decimal; values in the brackets point to the fact that the variance was bigger in the first 30-year period that is, they represent the Sd_1^2/Sd_2^2 ratio.

Conclusion

The main research objective of the study was to determine whether the differences in the change of air temperature and precipitation sums between the two 30-year periods (1951-1980 and 1981-2010) are significant or not. Calculations have been done on annual level for mean, mean maximum and mean minimum temperatures, as well as for precipitation sums. Obtained results for all three temperature parameters, maximum values in particular, show that the 1981-2010 period was significantly warmer in relation to pervious three decades. Also, there are significant changes in mean annual precipitation sums between the two observation periods on the coast and locally, in the western part of the country. If we look at the whole period, there is a slight aridization, except on far northeast of the country, but this precipitation decrease is insignificant in most parts of Montenegro. Yet, annual precipitation trend is positive in almost the whole area of Montenegro during the 1981-2010 period. Mean annual and mean annual minimum temperature fluctuations during the two observation periods are insignificantly different in most parts of Montenegro. The results show that variances of average annual precipitation sums during these two observation periods are also insignificantly different. The highest and significant dispersion increase on 13 stations in the 1981-2010 period, compared to the 1951-1980 period, was obtained for mean annual maximum temperature.

Further research should be focused on determining the cause of the changes of the two most important climate elements. In this context, a particular attention should be paid to the influence of the changes in atmospheric circulation and to the anthropogenic greenhouse effect.

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