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ANALYSIS AND PROJECTION OF SUMMER TEMPERATURE REGIME IN BELGRADE

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Abstract: Multitude of meteorological parameters defines weather and it continuously oscillates around the average climate values. Although patterns repeat after a certain period, nevertheless they virtually are never identical with preceding cases. They have different intensity, duration and consequence. However, some lawfulness of repetitiveness of patterns and meteorological parameters were observed and they can be described and defined by the indices of circulation. In this paper, we analyze the repetitiveness of hot and cold summers in Belgrade, which are defined by temperature and number of days with maximum temperature above a certain value. The analysis is focused on a very hot summer, which poses a potential threat due to rainfall and drought deficit, and favorable conditions for forest fires. By spectral and graphical method we observed lawfulness of their repetitiveness and on the base of that we made we made projections of temperature regime. The result indicates that in the next 30-35 years the number of days with the maximum daily temperature equal to or greater than 35°C decreases and in the equally long time again increases. Because the temperature correlates with the number of days with the maximum daily temperature, the average summer temperature should have an oscillation of about 65 years like trend of the number of days.

Key words: warm summers, repetitiveness, number of days with tmax=>35°C, projection

Introduction

Weather, expressed through numerous meteorological parameters, continuously oscillates around the average, equilibrium state, known as climatologically average values. Weather patterns repeat after some period, but they are never the same. There is always some difference in their intensity and duration. If we could find lawfulness of repetitiveness some meteorological parameters or weather patterns, we could make their prediction. Cyclic or periodical changes in climatology have been researched by many authors (Munoz, Ojeda, & Sanchez-Valverde, 2002; Klyashtorin, Borisov, & Lyubushin, 2009; Beecham & Chowdhury 2010; Humlum, Solheim, & Stordahl, 2011). There are a lot research papers about period of different index of circulation, as NAO (North

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Atlantic Oscillation), AO (Arctic Oscillation), PDO (Pacific Decadal Oscillation), LSO (Luni-Solar Oscillation), AMO (Atlantic Multi-decadal Oscillation) and cycles of Solar activity. For the region of Belgrade Paskota, Vujović, and Todorović (2013a) establish the correlation between some of these indexes and the repetitiveness of cold winters that are characterized by temperature and snow depth. Namely, they found that periods of snow-related variables (number of days with snow cover, absolute maximum of snow depth and sum of daily snow depth) could be related to LSO, and LSO is unmistakably correlated to the Arctic Oscillation (AO) (De Silva & Avissar 2005), where AO is the most dominant atmospheric phenomenon in winter. This finding can improve predictability of the patterns, because the occurrences of the LSO peaks are highly predictable. Furthermore, the same authors found that periodicity of snow variables corresponds to the double 11 year solar cycle (Erlykin, Sloan, & Wolfendale, 2009) and to the 22-years basic rotation period of Sun's magnetic field (Tlatov & Makarov, 2005). In some previous papers, the authors have noticed that there were some distinguishable periods with both ascending and descending temperature trends (Vujović, Todorović, & Paskota, 2007). Vujović and Todorović (2008) showed that number of days with minimum and maximum temperatures exceeding the selected thresholds increases with rising mean summer temperatures in Belgrade region. They found that a 1°C increase in the mean summer temperature results in eight additional days with maximum temperature ≥30°C.

In this paper, the analysis is pointed to a very warm summers that could be potential natural hazards because of deficit of precipitation, long-period drought and existence of good conditions for forest fires (Todorović, Radovanović, & Stevančević, 2007). We will present a short analysis of repetitiveness of warm (WS) and less warm (LWS) summers at Belgrade region in past. In addition, we will dare to give theirs projection in the next few decades.

The method

In this paper, the standard meteorological definition of summer season has been adopted – a summer starts on June 1 and ends on August 31. Nevertheless, we included September to calculate number of days with maximum daily temperature greater than 35°C because it is part of warm season. We used the data set consists of the summer mean temperature and the summer maximum daily temperature. These data were collected at Belgrade Meteorological Observatory (φ=44.8°N, λ=20.5°E, h=132 m), Serbia, for the period 1888-2013 (126 consecutive summers). The values of summer mean temperature were calculated according to the traditional equation (RHSS, 1987): t=

(t7+t14+2*t21)/4, where t7, t14 and t21 are temperatures observed at the climatologically times of 7, 14 and 21 h, respectively.

The data set was analyzed using correlation and regression analysis and spectral analysis. Correlation and regression analysis is well-known methods and we will not descript them here in detail. Spectral analysis is a mathematical method for detection of regular cyclical patterns or periodicities. We used here traditional non-parametric periodogram technique. Whittle (1952) showed that the periodogram gives the best maximum likelihood estimate of the frequencies. Because of that, we decided to search for repetitiveness and cyclic nature of the data using spectral analysis. Before performing this method, linear trends were removed from all variables where they were detected.

Results

We started the analysis with the simple linear regression of the mean summer and absolute maximum summer temperature for the period 1888-2013 (Fig. 1). Warm summers at Belgrade represented by temperature regime have some kind of lawfulness of repetitiveness. Vujović, Todorović, & Paskota, (2007) showed the maximum increase in mean and maximum temperatures was in the sub-period 1977-2006, while the maximum increase in minimum temperatures was in the sub-period 1913-1946. There are periods with increasing trend and periods with decreasing trend of the mean summer temperature, Fig. 1. The characteristic years that separate these periods are 1913 and 1976, with the lowest mean summer temperatures. The period between these years is 63 years. The characteristic years with the highest mean summer temperatures are 1946 and 2012. The period between them is 66 years. When analysis was conducted with the 5-years moving average of the mean summer temperature, very similar periods are obtained (64 and 66 years).

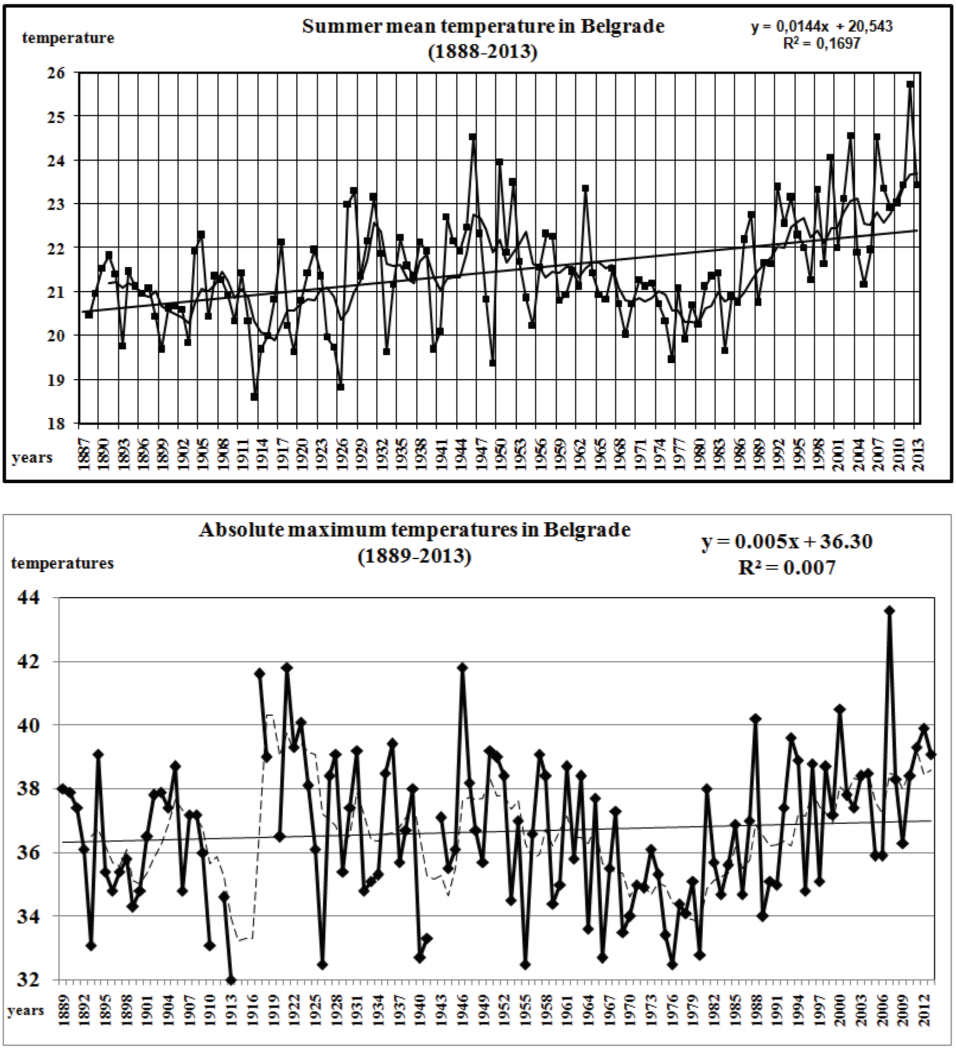


Figure 1. The mean summer temperature (the upper panel) and absolute maximum temperature (the lower panel) at Belgrade in the period 1888-2013. The average value of the mean summer temperature is 21.5°C. Linear regression and 5-years moving average are shown. There were missing data for absolute maximum temperature for years 1911, 1914-1916, 1919 and 1942.

After that, we calculate number of days with the maximum daily summer temperature (tmax) higher then 35°C for the period 1889-2013 (Fig. 2). Years with higher or smaller number of days with tmax ≥ 35°C are also grouped, and based on 5-years moving average we have period of 65 years between them. That period is similar to the period of AMO. As we already mentioned, number of days with extremely maximum temperatures exceeding the selected thresholds increases with rising mean summer temperatures (Vujović & Todorović, 2008). Furthermore, we could extract the period when number of days with tmax ≥ 35°C was frequently > 10 (1917-1952, 11 out of 36 years, and 1988-2012, 7 out of 25 years). There is a period when number of days with tmax ≥ 35°C was frequently smaller than 10 (1953-1987, 0 out of 35 years). Therefore, there are sub-periods with consecutive WS and LWS. From previous analysis we can concluded that one period (or wave) with WS and LWS has duration of 71 years (1917-1987). This value is similar to the previous calculated periods. Actual period with WS has duration from 1988 (25 years) and it is not finished yet. Paskota, Todorović, & Vujović (2013b) showed that the period 1991-2008 on the local level represents the pattern with dominantly warm years, while the period 1888-1910 represents patterns with low temperature.

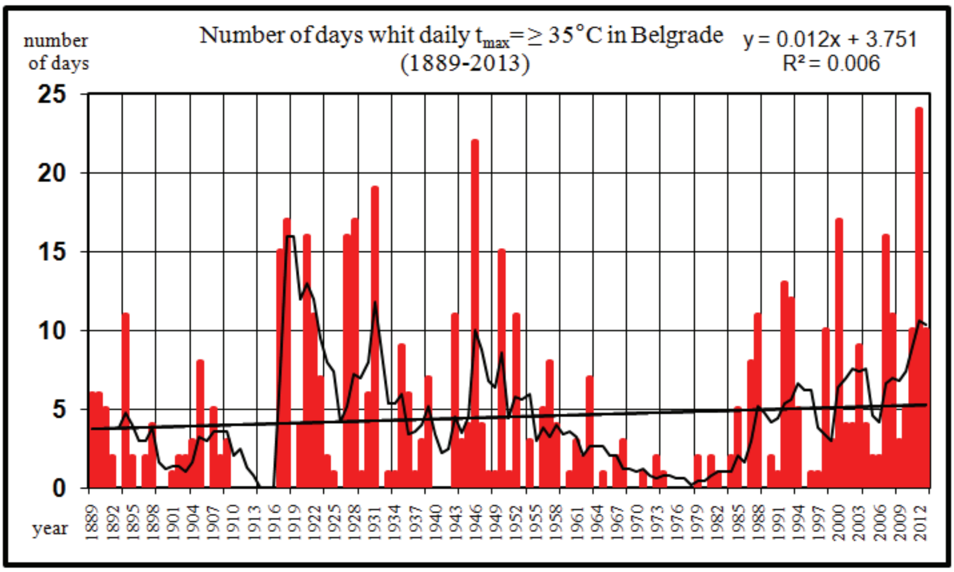
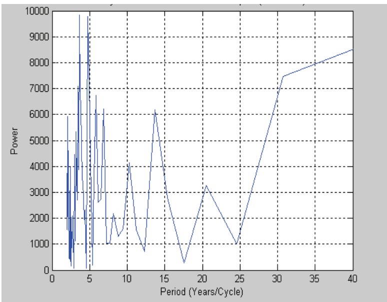


Figure 2. Number of days with the maximum daily temperature ≥ 35°C at Belgrade during the period 1889-2013. Five-years moving average are shown. There were missing data for years 1911, 1914-1916, 1919 and 1942.

Spectral analysis of number of days with tmax ≥ 35°C is shown in Fig. 3. It had showed that number of days with tmax ≥ 35°C have three separated periods of repetitiveness of 4-5 years, 14 years and 31 years.

a)



b)

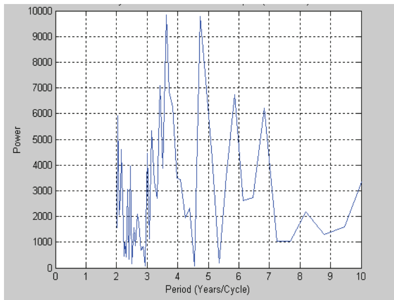


Figure 3. Periodograms of number of days with tmax ≥ 35°C: a) period of 40 years; b) extracted period of 10 years.

Table 1. The years with the similar summer temperature regime. The data in columns are: 1 – the number of the characteristic year, 2 – the year, 3 – the number of days with tmax ≥ 35°C in the year written in the column 2, 4 – the year, 5 - the number of days with tmax ≥ 35°C in the year written in the column 4, 6 – the period between years in the columns 2 and 4. In the inter-rows (the shaded) the period between the years in the same column is given.

The characteristic maxima						The characteristic minima					
1	2	3	4	5	6	1	2	3	4	5	6
1	1918	17	1985	5	67	1	1913	0	1976	0	63
	3		3				13		13		
2	1921	19	1988	11	67	2	1926	0	1989	0	63
	6		4				3		2		
3	1927	16	1992	13	65	3	1920	4	1983	0	63
	1		1				3		4		
4	1928	17	1993	13	65	4	1929	1	1991	1	62
	7		7				3		4		
5	1935	9	2000	17	65	5	1932	0	1995	0	63
	8		7				8		10		
6	1943	11	2007	16	64	6	1940	0	2005	4	65
	3		5				1		1		
7	1946	22	2012	24	66	7	1941	0	2006	4	65
							3		3		
						8	1944	3	2009	3	63
Mean value of the 6 column:					65.5	Mean value of the 6 column:					63.38

Analysis of the mean summer temperature and number of days with tmax=>35°C links the years with similar values of these parameters in some way. Table 1 gives the years and the periods between them. The main criterion was the number of days with tmax=>35°C. As a correction factor, we used the mean summer temperature. As it could be seen from Table 1, the average periods between the characteristic years are 65.5 years (maximum number of days with tmax=>35°C) and 63.4 years (minimum number of days with tmax=>35°C).

Based on the observed cyclic appearance of WS and LWS it could be to some extent perceive theirs future oscillations. The prediction consists of determination of the characteristic years with WS and LWS and theirs number of days with tmax=>35°C, repetitiveness, the mean summer temperature and trend of both parameters.

In Table 2, in the column 6, the period between the years in the columns 2 and 4 is 65 years for both types of characteristics years. Values in the column 5 are calculated using increasing trend of number of days with tmax=>35°C (1 day per 100 years, Fig. 2). Based on calculated characteristic years from Table 2, and oscillations and trend of the mean summer temperature, Fig. 4 was made

Table 2. The projection of number of days with tmax=>35°C in Belgrade. The meaning of data in the columns 1 – 6 is the same as in Table 1.

The characteristic maxima						The characteristic minima					
1	2	3	4	5	6	1	2	3	4	5	6
1	1950	15	2015	16	65	1	1949	2	2014	5	65
	2		2				4		4		
2	1952	11	2017	12	65	2	1953	0	2018	3	65
	5		5				2		2		
3	1957	8	2022	9	65	3	1955	0	2020	2	65
	6		6				4		4		
4	1963	7	2028	8	65	4	1959	0	2024	2	65
	5		5				5		5		
5	1968	3	2033	4	65	5	1964	0	2029	1	65
	5		5				6		6		
6	1973	2	2038	3	65	6	1970	0	2035	1	65
	8		8				6		6		
7	1981	2	2046	3	65	7	1976	0	2041	1	65
	4		4				7		7		
8	1985	5	2050	6	65	8	1983	0	2048	1	65
	3		3				3		3		
9	1988	11	2053	12	65	9	1986	0	2051	2	65
	4		4				3		3		
10	1992	13	2057	14	65	10	1989	0	2054	2	65
	1		1				6		6		
11	1993	13	2058	14	65	11	1995	0	2060	3	65
	7		7				10		10		
12	2000	17	2065	18	65	12	2005	4	2070	5	65
	7		7				1		1		
13	2007	16	2072	17	65	13	2006	4	2071	5	65
	5		5				3		3		
14	2012	24	2077	25	65	14	2009	3	2074	4	65

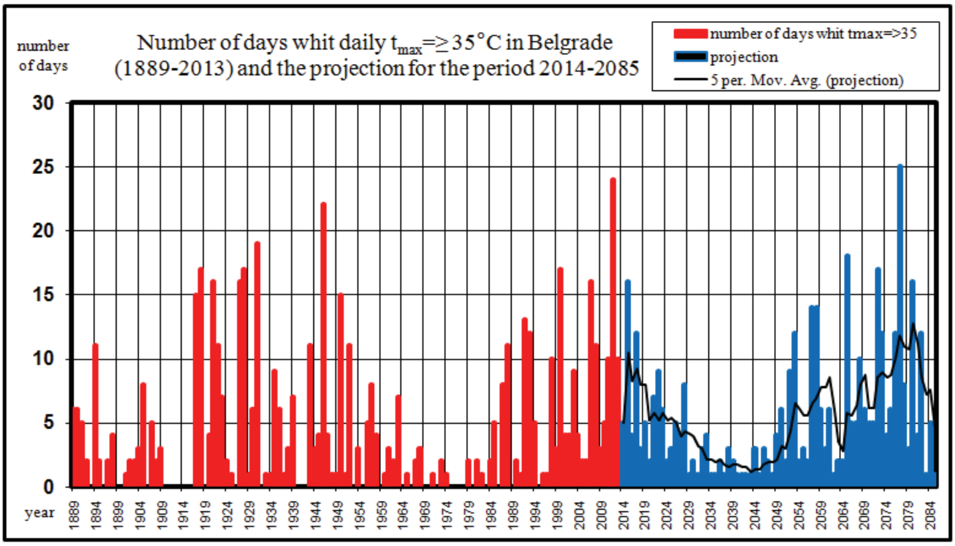


Figure 4. The number of days with tmax=>35°C in Belgrade for the period 1889 – 2013 and the projection for the period 2014 – 2085 along with 5-years moving average.

Discussion

Analysis of the mean summer temperature and number of days with tmax=>35°C links the years with similar values of these parameters in some way. It is somewhat possible perceive their future oscillations based on observed periodicity of warm and less warm summers.

Repetitiveness of number of days with tmax=>35°C in the period 1889 – 2013 give us the way to make projection for the future decades. Spectral analysis and graphical methods showed decrease of the number of days with tmax=>35°C in the following 30 to 35 years, and after that period a new increase. Therefore, a one full cycle is about 60 to 70 years, which corresponds to the period of Atlantic Multi-decadal Oscillation. Projection of the mean summer temperature is in direct correlation with projection of number of days with tmax=>35°C. Based on that, we could expect decreasing trend of the mean summer temperature in following three decades.

The projection of the number of days with tmax=>35°C is calculated on the basis of the average repetitiveness (65 years). Therefore, it is not realistic to expect that the projected number of days each year to be realized, there are possible deviation for 1-2 years. The deviation is possible for the number of days, also. The main objective of the projection of the summer temperature regime there was detection period and the trend of warm and less warm summer.

The mean yearly temperature has increasing trend in the period 1887-2011 (Paskota, Vujović, & Todorović, 2013a). The major contribution to this increase is the winter minimum temperatures, and this is consequence of urbanization (spreading of the city area and city's heat island). Because of that, the projected decreasing trend of the mean summer temperature could be compensated by possible increasing trend of the winter temperatures. As a result, we could expect a smaller decrease in the mean yearly temperatures.

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