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Trends in extreme summer temperatures at Belgrade

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With 5 Figures

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Summary

Trends in extreme temperatures have been investigated for the Belgrade temperature record (1975–2003) to assess how an increase in the mean summer temperatures is related to changes in the extreme maximum and minimum temperatures. The rising mean summer temperatures at Belgrade are associated with a substantial increase in the occurrence of extreme maximum temperatures. Two statistical models for climate change (changing mean with constant standard deviation, and changing mean and standard deviation) indicated that the changing mean was dominant, because the observed trend in standard deviation was small.

1. Introduction

Changes in climate variability and extreme climate events received increased attention during the last decade of the 20th century. In particular, attention has focused on trends in extreme temperature and precipitation (Balling et al., 1990; Tarleton and Katz, 1995; Groisman et al., 1999; Easterling et al., 2000) due to the frequently large loss of human life and large economic losses.

Many climate models have predicted significant increases in global and regional temperatures, as greenhouse gases are added to the atmosphere (Hansen et al., 1988; Karl et al., 1991). In these models, the changes in temperature correspond to changes in the mean temperature on monthly, seasonal and annual time scales. However, a given adjustment in the mean temperature may result from a variety changes in diurnal temperature, e.g. in the minimum and maximum temperatures (Unkašević, 1990).

Temperature records across the world indicate that there has been an increase in the mean global temperature of about 0.6 °C since the start of the 20th century (Nicholls et al., 1996), and that this increase is associated more strongly with a warming in daily minimum temperatures, rather than with a change in maximum temperatures (Easterling et al., 1997).

Temperature extremes are a key aspect of any climate change because ecosystems and societal responses are most sensitive to them. Moreover, changes in temperature extremes are often most sensitive to inhomogeneous temperature monitoring practices, making the assessment of change more difficult than assessing a change in the mean.

Mearns et al. (1984) and Hansen et al. (1988) concluded that relatively small changes in the mean temperature could produce substantial changes in the frequency of temperature extremes. So, in the present analyses, the primary focus was to determine the empirical link between the observed increased temperature at Belgrade, and the frequency of extreme maximum and minimum summer temperatures.

The increasing temperature at Belgrade is related to heat island processes (Unkašević, 1991), and probably, the greenhouse effect (Tarleton and Katz, 1995), so these records may serve as a valuable tool to monitor potential greenhouse warming.

2. Database

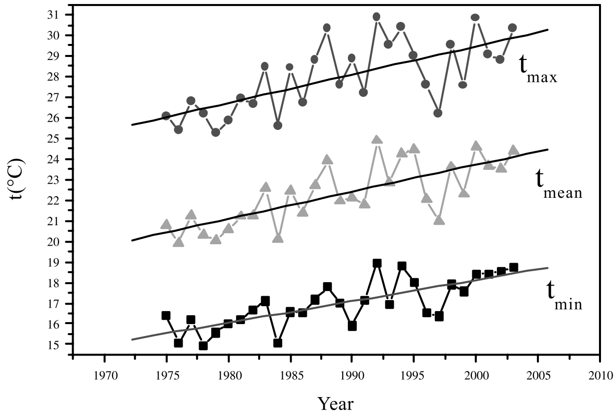
Daily maximum, minimum and mean temperatures were collected from a database available for July and August, from 1975 to 2003. This period was chosen because of the rapid urbanization of Belgrade after the year 1975. The observations were taken at the Belgrade Meteorological Observatory, located in the city center in the park area. There were no station moves during the study period and the data set has no missing records. Minimum and maximum temperatures were measured by Schneider's thermometers. Technical and critical controls of these measurements were made by the National Meteorological Service. The station is situated at 131.6 m above mean sea level and its geographical coordinates are $\varphi = 44°48'$ N and $\lambda = 20°28'$ E.

Belgrade is located in a continental climatic region: the maximum mean daily temperature occurs in July or August, while the minimum occurs in January or February. The Belgrade basin has an estimated population of 2 million, and covers an area of approximately 322 km^2, with the Avala hill (505 m a.s.l.) to the south, and lowlands to the north and west.

3. Statistical data analysis

Relatively little work has been completed in relation to changes in the frequency of extreme temperature events, i.e. in the number of days that various temperature thresholds are exceeded (Easterling et al., 2000).

A linear increase in the mean summer (July and August) temperature was observed (Fig. 1), with more warming in the maximum than in the minimum temperatures. The daily maximum and minimum temperature records were analysed to determine the influence of the rising mean summer temperatures to the frequency of extreme, i.e. daily maximum and minimum temperatures at Belgrade.



t_{max}	$Y = 25.89504 + 0.13754 * X$
t_{min}	$Y = 15.42152 + 0.10403 * X$
t_{mean}	$Y = 20.2977 + 0.13167 * X$

Fig. 1. Trends of changing the summer (July–August) temperatures during the period 1975–2003 at Belgrade

Figure 1 shows that the mean summer temperature at Belgrade increased at rate of 0.1316 °C/yr. However, the rate of increase in the seasonal mean maximum temperature was greater (0.1375 °C/yr) than the rate of increase in the seasonal mean minimum temperature (0.1040 °C/yr). This increase in the seasonal mean maximum temperature can be explained by the existence of the urban heat island, enhanced aerosols and clouds in the urban atmosphere. Also, the Belgrade Meteorological Observatory is surrounded by high concrete buildings and high trees that limit ventilation and probably caused an increase of the mean summer maximum temperatures.

Statistics describing the relationship between the occurrence of extreme maximum and minimum temperatures, and mean summer temperatures are shown in Table 1. Note that $\bar{X}$ is defined as the mean number of days greater than or equal to ($\geq$) a certain threshold divided by the mean summer temperature (Balling et al., 1990). SD, μ_3 and μ_4 are the standard deviation and the standardized coefficients of skewness and kurtosis, respectively. R_s and R_p signify the Spearman rank-order and the Pearson product-moment correlation coefficients, respectively.

Table 1 shows that $\bar{X}$ for the minimum temperature decreases faster with an increasing threshold than $\bar{X}$ for the maximum temperature.

Table 1. Statistics describing the relationship between the occurrence of extreme maximum and minimum temperatures above a defined threshold, and the mean summer temperature during the period 1975–2003 at Belgrade

	$\bar{X}$	SD	μ_3	μ_4	R_S	R_P
max ≥ 30	27.303576	9.4277026	0.9619168	−0.2124185	0.58	0.55
max ≥ 31	20.926754	7.3394919	0.9935351	−0.1280893	0.48	0.67
max ≥ 32	15.582798	5.5353342	1.0472439	0.0810447	0.46	0.33
max ≥ 33	10.957356	3.9611295	1.0815436	0.2775709	0.63	0.37
max ≥ 34	7.0953373	2.6571631	1.042844	0.0941945	0.58	0.36
max ≥ 35	4.4458126	1.7192479	1.1076258	0.325889	0.29	0.41
max ≥ 36	2.5148031	0.9981124	1.2422927	1.5	0.27	0.17
min ≥ 18	30.851245	11.04	1.13	0.27	0.72	0.59
min ≥ 19	21.510548	7.75	1.24	0.84	0.51	0.65
min ≥ 20	13.023087	4.88	1.15	0.48	0.68	0.55
min ≥ 21	7.8138524	3.01	1.21	0.89	0.61	0.45
min ≥ 22	4.086555	1.63	1.05	0.63	0.35	−0.2

Note: $\bar{X}$ is the mean number of days ≥ a threshold temperature in July and August, SD is standard deviation (in days), μ_3 and μ_4 are the standardized coefficients of skewness and kurtosis, R_S is the Spearman rank-order correlation coefficient for the relationship between the mean seasonal temperature and the number of occurrences ≥ selected temperatures, R_P is the Pearson product-moment correlation coefficient for the relationship between the mean seasonal temperature and the number of occurrences ≥ selected temperatures

The standardized coefficients of skewness and kurtosis calculated for the 29 years of records have absolute values below 2.02, indicating that the values of $\bar{X}$ are approximately normally distributed. Also, the results indicate that the more extreme maximum or minimum temperatures have frequency distributions that are dominated by positive skewness and peakedness. The values obtained for the Spearman rank-order correlation coefficient and the Pearson product-moment correlation coefficient are positive, greater than 0.31, and are statistically significant.

In each case, the results show that the number of days with maximum and minimum temperatures exceeding the selected high values of 30 to 36 °C and 18 to 22 °C, respectively, increase significantly with rising mean summer temperatures (Fig. 2).

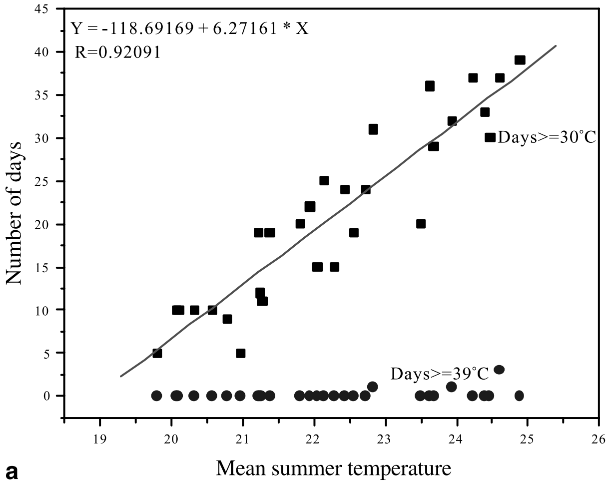
It is interesting that the rising summer temperatures appear to have an almost equal impact on the number of days of extreme maximum and minimum temperatures above certain tresholds (Fig. 2). Selected examples in Fig. 2 show that a 1 °C increase in the mean summer temperature results in six additional days with maximum temperature ≥30 °C and minimum temperature ≥18 °C. However, the impact of the rise in summer temperature dwindles to an increase of less than one day for maximum temperatures of 39 °C and minimum temperatures of 25 °C.

4. Models used

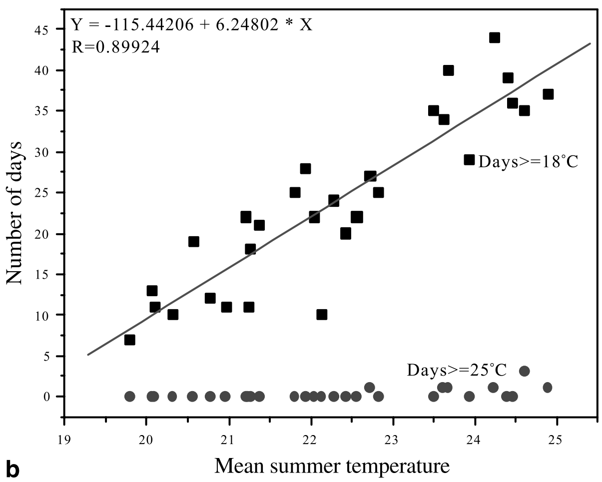
The analyses presented in Section 3 indicate that the rising mean seasonal temperature reflects a significant increase in the number of days with high maximum and minimum summer temperatures. However, understanding changes in temperature variability and temperature extremes is made difficult by interactions between the changes in the mean and variability (WMO, 2001).

When extreme temperatures are distributed normally (Table 1 in Section 3), a non-stationary distribution implies changes in the mean, or standard deviation. In such a distribution, an increase in the mean temperature, without a change in the standard deviation, reflects new record high temperatures. Conversely, an increase in the standard deviation, without a change in the mean temperature implies an increase in the probability of hot extremes as well as in the absolute values of those extremes. Increases in both the mean and the standard deviation are also possible, which reflects (in this example) the probability of hot extremes, with more frequent hot events, and with more extreme high temperatures (WMO, 2001).

Tarleton and Katz (1995) established that the tendency to overestimate the frequency of extreme events can be reduced by allowing for the observed change in the standard deviation.



a



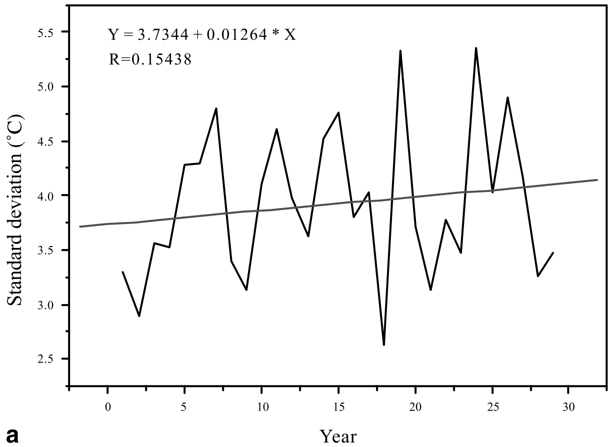
b

Fig. 2. Relationships between occurrence of selected: **a**) maximum temperature ($\geq 30\,°C$ and $\geq 39\,°C$), **b**) minimum temperature ($\geq 18\,°C$ and $\geq 25\,°C$) and the mean summer temperature during the period 1975–2003 at Belgrade

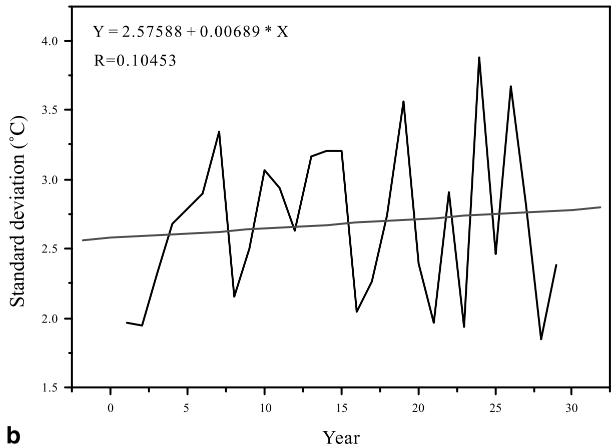
Figure 3 shows the time series of the standard deviation of daily maximum and minimum temperatures. In this case linear trends of about 0.0126 °C and 0.0069 °C per year were obtained. Although these observed trends towards a change in the standard deviation appear to be small, the frequency of extreme events is known to be quite sensitive to any such changes (Katz and Brown, 1992).

The probabilities of extreme maximum and minimum temperatures are estimated by making use of the normal distribution $F(t, \bar{X}_y, SD_y)$, where t denotes threshold, and $\bar{X}_y$ and SD_y relate to the mean and standard deviation for the y^{th} year, respectively. Therefore, the probability that the extreme temperature X exceeds a fixed threshold t on a given day during the summer of the y^{th} year is expressed as:

$$P(X > t) = 1 - F(t, \bar{X}_y, SD_y). \qquad (1)$$



a



b

Fig. 3. Time series of the standard deviation of daily temperature along with trend during summer for the period 1975–2003 at Belgrade: **a**) maximum and **b**) minimum

For simplicity, any effect of the annual cycle on the mean and standard deviation during the summer of a given year is ignored (Tarleton and Katz, 1995). In the present case we used two models:

1) changing mean with constant standard deviation; and
2) changing mean and standard deviation.

The linear trends for the rising means in the maximum and minimum temperatures, presented in Fig. 1, allows the calculation of coefficients (a_1 and b_1) in the equation in the form of:

$$\bar{X}_y = a_1 + b_1(y - 1975), \quad y = 1975, 1976, \ldots, 2003. \qquad (2)$$

The least-squares estimates for this trend (line 2) are: $a_1 = 25.89\,^\circ\mathrm{C}$ and $b_1 = 0.13754\,^\circ\mathrm{C}$ per year for the maximum temperature; and $a_1 = 15.42\,^\circ\mathrm{C}$ and $b_1 = 0.10403\,^\circ\mathrm{C}$ per year for the minimum temperature. In this model, the standard deviation was held constant for the entire period of 1975–2003. The estimate of the standard deviation was 3.92 °C for the maximum temperature, and 2.68 °C for the minimum temperature.

In the second model the standard deviation was permitted to change linearly (Fig. 3), in the form of:

$$SD_y = a_2 + b_2(y - 1975), \quad y = 1975, 1976, \ldots, 2003. \tag{3}$$

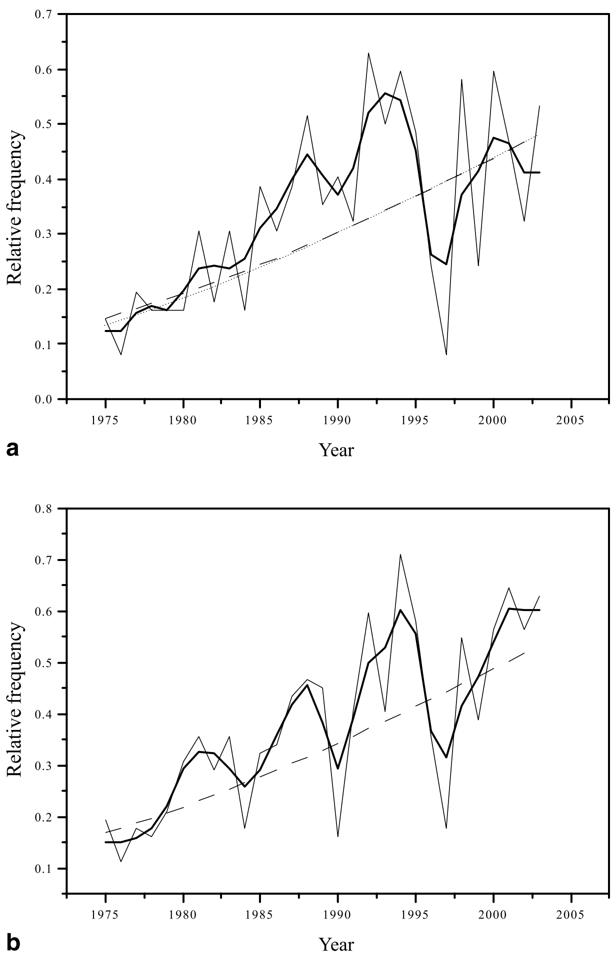


Fig. 4. Probabilities of maximum and minimum temperatures in the summer at Belgrade exceeding a threshold **a**) $\geq 30\,^\circ\mathrm{C}$ and **b**) $\geq 18\,^\circ\mathrm{C}$: observed relative frequency (solid line), smoothed relative frequency (bold line), model 1 (changing mean, with constant standard deviation estimate-dashed line) and model 2 (changing mean and standard deviation-dot line)

The least-squares estimates for this trend (line 3) are: $a_2 = 3.73\,^\circ\mathrm{C}$ and $b_2 = 0.01264\,^\circ\mathrm{C}$ per year for the maximum temperature; and $a_2 = 2.57\,^\circ\mathrm{C}$ and $b_2 = 0.00689\,^\circ\mathrm{C}$ per year for the minimum temperature.

The probabilities of extreme temperature on an observed and calculated basis are represented in Fig. 4. Figure 4 shows that the probabilities of the summer maximum and minimum temperatures exceeding a defined threshold rise from the year 1975 to 2003. Also, it is evident that even though the changes imposed on the means and standard deviations are linear, the relationship between the probability of extremes and the mean or standard deviation is highly nonlinear (Mearns et al., 1984). To remove some of the year to year fluctuation, smoothed versions of maximum and minimum temperature were obtained using the Hanning method (Tukey, 1977).

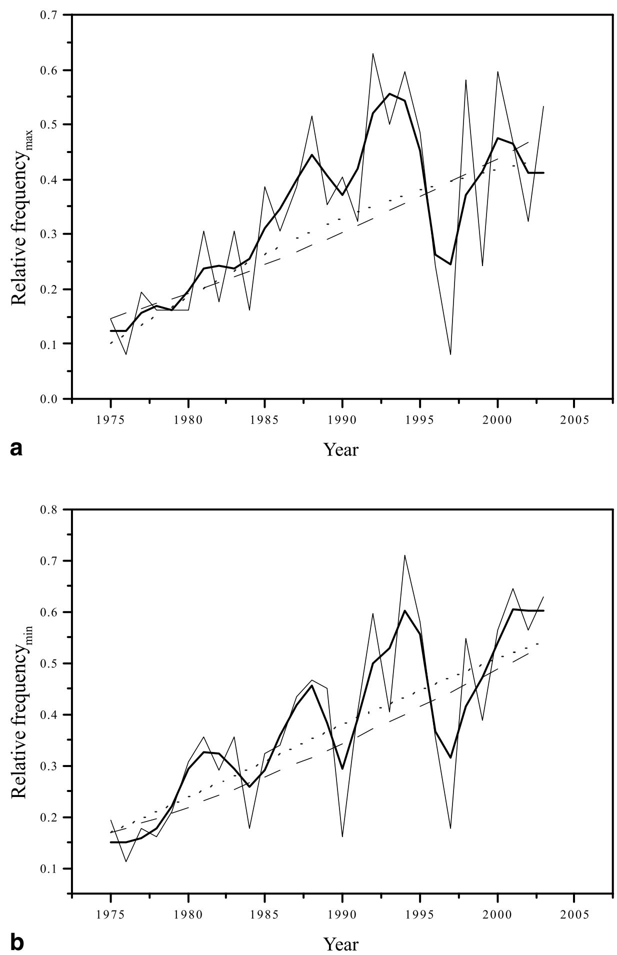


Fig. 5. Same as in Fig. 4, but with model 1 with nonlinear trends to the mean maximum (**a**) and minimum (**b**) temperatures (dot line) instead model 2

Figure 4a shows that differences between two models are negligible, because the observed trend towards a change in the standard deviation is small (Fig. 3a). Also, the second model is virtually indistinguishable from the first model, and is not included in Fig. 4b. These results are consistent with those obtained for the other maximum and minimum temperature event thresholds.

To improve model 1, we used nonlinear trends for the mean summer maximum and minimum temperatures in the form of:

$$\bar{X}_y = a_1^* + b_1^* \exp[-(y - 1975)/c_1], \quad y = 1975, 1976, \ldots, 2003. \tag{4}$$

with $a_1^* = 30.15\,°C$, $b_1^* = -5.13\,°C$ and $c_1 = 14.94$ year for the maximum temperature; and $a_1^* = 21.57\,°C$, $b_1^* = -6.13\,°C$ and $c_1 = 44.94$ year for the minimum temperature.

As shown in Fig. 5, and from the least-squares estimates, model 1 with the inclusion of nonlinear trends for the mean temperatures, produced a better fit of the data.

5. Trends for absolute daily extremes

Absolute daily extremes of both maximum and minimum temperatures during the summer at Belgrade showed a strong trend towards an increase for the 1975 to 2003 period. The absolute maximum temperature increased to a greater extent (0.1644 °C/yr) than the absolute minimum temperature (0.1166 °C/yr). Also, the rate of increase in the summer absolute maximum and minimum temperatures at Belgrade was larger than the rate of increase in the summer mean maximum and minimum temperatures (Fig. 1). Similar results were obtained for eastern China by Gong et al. (2004).

Finally, a statistical analysis of absolute daily extremes for Belgrade, during the above mentioned period, was performed by using a normal distribution. Testing the fit of an empirical probability density function to the normal density function has be done by using the chi-squared goodness-of-fit test. The condition $\chi^2 < \chi^2_{0.05}$ is satisfied by the normal probability density function for the absolute daily maximum temperatures ($5.31 < 11.07$), and is approximately satisfied for the absolute daily minimum temperatures.

6. Conclusions

In our analysis of the summer trends in extreme temperatures at Belgrade during the period 1975–2003, we can conclude that:

- There was a linear increase in the observed mean summer temperature, in the order of 0.1316 °C/yr, with more warming in the daily maximum temperature (0.1375 °C/yr), than in the daily minimum temperatures (0.1040 °C/yr).
- Rising mean summer temperatures reflect an increase in the number of hot days. For example, a 1 °C increase in the mean summer temperature reflects six additional days with ≥30 °C for the maximum, and ≥18 °C for the minimum temperature.
- The two models used to determine the probability of an extreme temperature exceeding a fixed threshold indicated that differences between the two models are negligible, because the observed trend towards a change in the standard deviation was small.
- A better result was obtained by using nonlinear equations to model trends for the change in mean summer maximum and minimum temperatures.
- The normal probability density function gave a good fit to the extreme temperature, as well as to absolute daily maximum and minimum temperatures.
- Also, the absolute maximum temperature exhibited a greater increase (0.1644 °C/yr) than the absolute minimum temperature (0.1166 °C/yr).

The results suggest that considerable caution should be used in predicting the occurrences of extreme temperatures from projected increases in the mean temperature levels alone.

Acknowledgements

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