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The yearly averaged air temperature in Belgrade from 1888 to 1987

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RESUMEN

Los datos de la temperatura del aire de Belgrado son analizados para puntualizar las variaciones causadas por los eventos naturales y las actividades humanas. En particular, la influencia del crecimiento de la ciudad sobre el promedio mínimo de temperatura es evidente.

ABSTRACT

Air temperature data of Belgrade are analysed to point out the variations caused by natural events and human activities. In particular, the influence of the growth of the city on the minimum average temperature is evident.

1. Introduction

There is a growing interest in studies on climate and its variations for the purpose of developing models for forecasting the climatic evolution of the planet and to discover any modifications introduced in it by human activities. The analysis of long series of meteorological data provides important information, of use in attaining these two interrelated objectives. Much work has been done on air temperatures, since variations in this parameter are considered more indicative of any climatic variations.

A first type of analysis deals with the study of temperature variations as a function of time, both in an attempt to find patterns and, when the data refer to the urban environment, to discover alterations induced in the temperature itself through human activity (urban heat island). A wide-ranging survey of the subject is contained in Oke (1974, 1979), Garstang *et al.* (1975) and Landsberg (1981), who examine the structures of the heat island as a function of the size and growth rate of the city.

In the present work, the mean yearly temperature data in Belgrade are analysed for the purpose of:

(i) reconstructing the history of this meteorological parameter, identifying trends and comparing the latter with those of other European cities, and

(ii) evaluating the effect of the city's growth on temperature trends.

In particular, after a short description of the data set used, an statistical analysis of the raw data is given to show that the minimum temperature trends differ from the medium and maximum ones. The trend analysis carried out using low-pass numerical filters confirms this characteristic which, by comparison with other data, is found to be shared by other cities. An analysis is then made of the urban island heat effect (Oke, 1974, 1979; Garstang *et al.*, 1975; Landsberg, 1981; Colacino and Lavagnini, 1982) and application of simple correlation models provides a satisfactory explanation of the minimum temperature trend.

2. Data used

The data analysed are typical of the Belgrade urban situation since they were recorded at the Meteorological Observatory of Belgrade located in the city center. The station is situated at 131,6 m above mean sea level and its geographical coordinates is $\varphi = 44^0$ 48 N and $\lambda = 20^0$ 28 E. Useful indication therefore can be inferred on the possible change of climate. Besides there is an increasing interest in research on climate and its variations for the purpose of building models which forecast the climatic change and modifications introduced in it by human activities.

The measurement began on July 1, 1887 with an ordinary mercury thermometer, maximum mercury thermometer and minimum alcohol thermometer.

For the periods of interrupted meteorological measurements and observations (July - December, 1914, October - December, 1919), the mean monthly air temperature values were interpolated in relation of the data for the stations Pančevo, Sremska Mitrovica and Indjija.

Hourly temperature observations as well as the temperature recording by using Bellani thermograph has been performed since 1894. During the Second World War there were homogeneity interruptions in maximum air temperature lasting from November 18, 1941 till March 31, 1943. In this period the air temperatures were measured by Assman aspiration thermometer.

Three recordings were generally made every day. The measurements were carried out at 07.00, 14.00 and 21.00 hr. Minimum and maximum temperatures were also recorded. With these values the mean daily temperatures were determined from which the monthly ones were obtained and used here. For each mean value the standard deviation was also calculated in order to verify the data, according to the ordinary criteria of the statistical distributions (e.g., the t distribution tables for $n > 30$).

Also, in order to apply statistical tests to a time series it is essential to know the type of the frequency distribution. To this end, mean, maximum and minimum air temperatures were tested for normality using Fisher's statistics. It has been found that the annual mean, minimum, and maximum air temperatures in Belgrade satisfy this criterion.

Besides, homogeneity test were carried out and adjustments were made to filter out inhomogeneities due to errors introduced by the instruments and observers changes.

3. Statistical data analysis

The annually averaged air temperatures are represented in Figure 1 (Rezultati osmatranja meteorološke opservatorije u Beogradu u periodu 1887-1986, 1987). The diagrams of this figure show the trends of these mean values in Belgrade. $\overline{T}$ is the mean annual temperature obtained from the mean daily temperatures. The mean annual minimum and maximum temperatures are Tm and

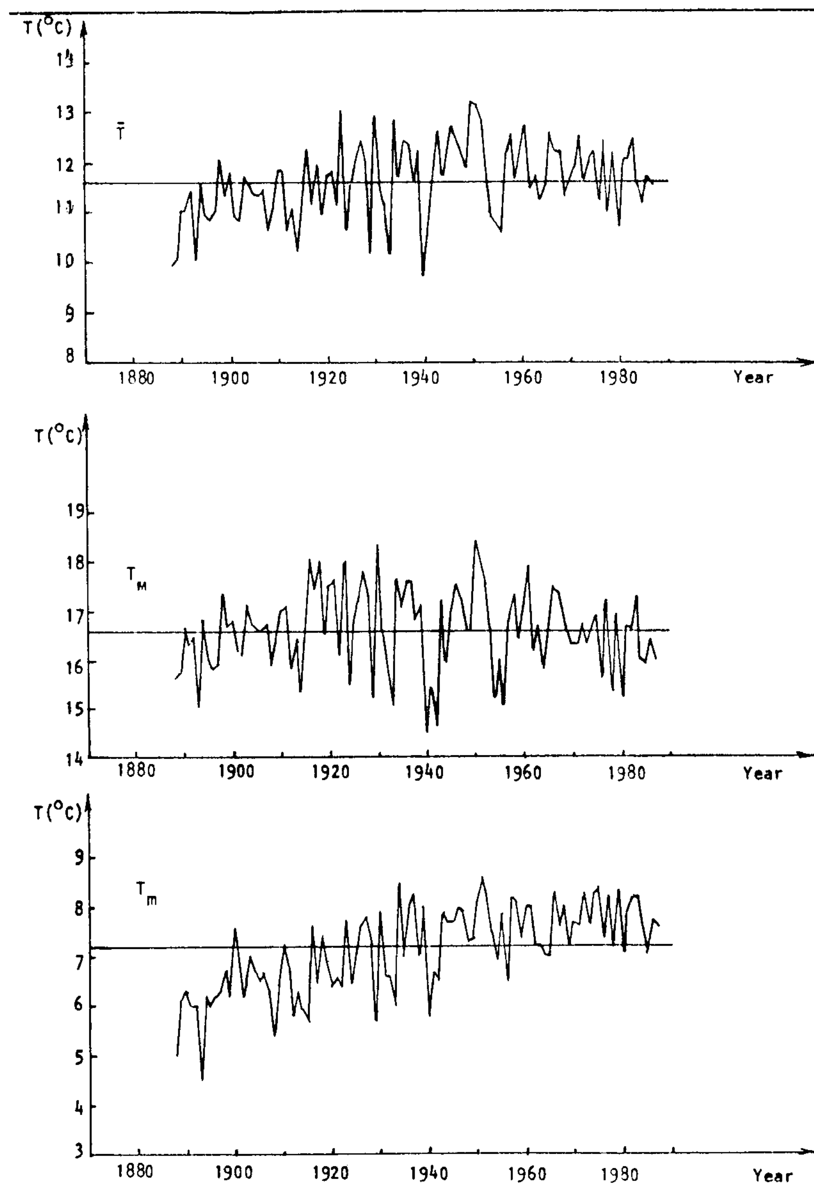

Fig. 1. Annual mean values of air-temperature in Belgrade.

T_M, respectively. The mean annual temperature for the whole 100 years period is 11.6°C. During the period 1888-1915 the annual means were generally under this value. After that, they tend to increase and temperature fluctuates more or less around the mean value. In Figure 2(a), the mean temperature distribution is given over the range 9.5 - 13.5°C, divided into 0.5°C intervals. This histogram shows that 90% of the values lie in the range 10.5 to 13.0°C. The values at the extreme end of the range are relatively low; the mean temperature occurred only twice in the 9.5 - 10.0°C interval, four times in the 10.0 - 10.5°C interval, and only three times in the higher 13.0 - 13.5°C interval. The distribution of the mean maximum temperatures show a similar trend to that of the mean temperatures. The mean value for the whole recording period is 16.6°C. In the period 1888 - 1915 the values are frequently below the mean value. In subsequent years, up to 1956 the value fluctuate strongly around the mean. Between 1957 and 1988 there are slight fluctuations around the mean value. Figure 2(b), shows the distribution of maximum temperatures: the histogram shows that most of them (93%) lie between 15.0 and 18.0°C. The minimum temperatures show a different pattern. During the period 1888 - 1915 the values are less than the mean (7.2°C).

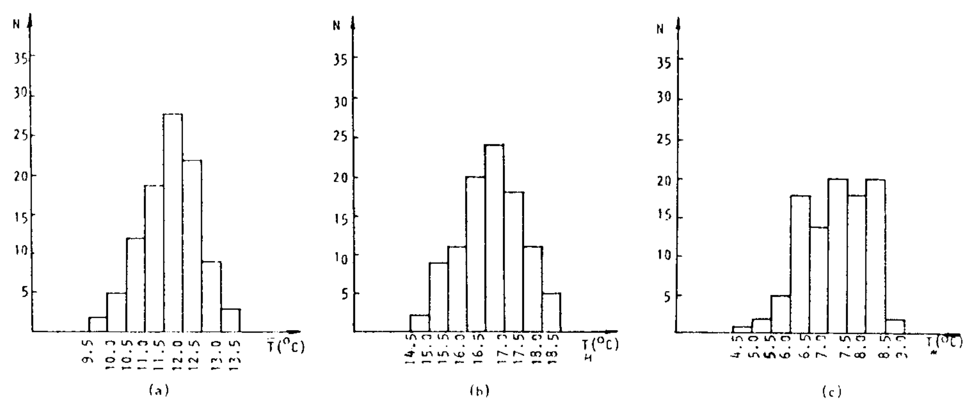

Fig. 2. Histogram distribution of the air-temperatures: (a) mean; (b) mean maximum; (c) mean minimum.

Between 1916 and 1944 the values were fluctuating around the mean. After 1944 there is a sharp increase, probably due to the growth of the city. This is confirmed in the distribution of values of Figure 2(c), in which the histogram show that maximum data concentration (90%) occurs in the 6.0 - 8.5°C interval. The data population of the intervals in the extreme ends of the range is very low and it is significant that temperatures of less than 6.0°C are found only in the period 1888 - 1905 and 1907 - 1915.

In order to get an overall idea of the trends, averages were taken for 10-year periods, starting from 1891. The results obtained are shown in Table 1. This first analysis clearly shows that while the mean and maximum temperatures show an increase in the years 1891-1950 ($\overline{T}$) and 1891-1930

Table 1. 10-year averaged air temperature in Belgrade

period	T_m(°C)	$\overline{T}$(°C)	T_M(°C)
1891-1900	6.2	11.1	16.3
1901-1910	6.5	11.2	16.5
1911-1920	6.5	11.3	16.8
1921-1930	7.0	11.7	17.0
1931-1940	7.2	11.5	16.6
1941-1950	7.5	12.1	16.6
1951-1960	7.7	11.9	16.6
1961-1970	7.5	11.7	16.8
1971-1980	7.8	11.7	16.3
1981-1989	7.9	11.9	16.6
1951-1989	7.7	11.8	16.6

(T_M), and a subsequent slight decrease during recent years, the minimum temperatures show a tendency to increase, also in the period 1981 - 1989. However, during the period 1951 - 1989, the maximum temperature values were around 16.6°C (equal to the averaged 100 yrs. value), while the mean temperature values were higher than averaged 100 yrs. value probably due to constant increase of the minimum temperature.

Mean and maximum temperatures are decreasing in the period 1971 - 1980, because the year of 1972 was the coldest winter since 1918, while 1981 and 1982 were among the five warmest winters during the last 100 years. From that reason, mean and maximum temperature are increased in the 1990's. So it is not possible to use Fig. 3 to calculate a value for the greenhouse effect which could be used to reduce the minimum temperatures.

In his recent paper Jones (1986) points out that the surface air temperature record for the last 100 years showed a general warming for Northern Hemisphere, amounting to about 0.4°C since 1880, a figure which fits well with the theoretical estimates of the increase of temperature which might be expected as a result of 15 - 20% increase of atmospheric CO_2. An increase of this order of magnitude (Wilson and Mitchell, 1987) is believed to have resulted from the burning of fossil fuels during the last hundred years, although the atmospheric concentration of CO_2 has

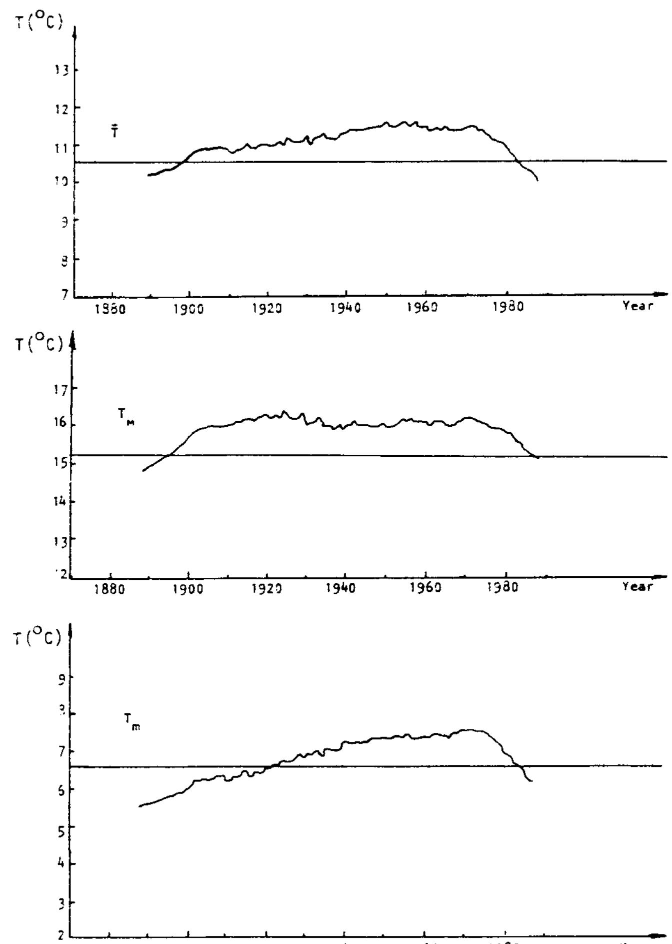

Fig. 3. Trends obtained by numerical filtering applied to Belgrade temperature data.

been actually measured only since 1958 and there is a large range of estimated pre-industrial values. Many other external factors (aerosols, solar flux, etc...) could cause temperature changes of the observed magnitude and further, any estimates of the expected climate change predicted from current theoretical models cannot as yet be very reliable because of the major feedbacks and other factors which are not yet taken into account in the models.

4. Trend analysis by means of low-pass filters

For a better description of large time scale behaviour of the Belgrade air-temperature, a numerical low-pass filtering technique was used. Through this technique each point in the time sequence is obtained as the weighted mean of the M samples preceding and of the M samples following it. The number M is the filter length and is chosen on the basis of physical criteria. If N is the number of the samples of the mean annual temperature (here N is the data set length), the trend is obtained from the relation

$$\hat{\chi}_T = \sum_{k=-M}^{M} h_k \chi_{t-k}, \qquad t = 1,\ 2, \ldots\ldots N. \tag{1}$$

The filter h_k used in the present analysis is an Ormsby filter (Ormsby, 1961; Colacino and Rovelli, 1983) defined by

$$h_k = \frac{\sin\ (2\pi f_1 k \Delta t)\ \sin\ (2\pi f_2 k \Delta t)}{2\pi^2 f_2 (k\Delta t)^2}, \tag{2}$$

with $f_1 = (f_r + f_c)/2$ and $f_2 = (f_r - f_c)/2$, where f_r and f_c are known as roll-off and cut-off frequency, respectively. In our case $\Delta t = 1$ yr. The advantage of this type of low-pass filter is that it has unit gain and zero phase shift; that is, it does not alter the signal amplitude in the passing band and does not introduce any shifting in the various harmonics. Filter characteristics may be easily visualized by means of a frequency response curve (Figure 4). In order to achieve high filtering accuracy (1%) it is convenient to select M using the expression

$$M = \frac{2 f_N}{f_r - f_c}, \tag{3}$$

which, in this case, gives $M \approx 22$. In order to eliminate fluctuations with a period less than 20 yr, $f_r = \frac{1}{20}$ cycles per year and $f_c = \frac{1}{100}$ cycles per year were selected. f_N is defined as the Nyquist frequency and is linked to the sampling rate by the expression $f_N = 1/2 \cdot \Delta t$. Finally, it must be emphasized that the results of this type of analysis are less accurate at the initial and final boundary of the series than at the intermediate range, as the weighted means are affected asymmetrically because of the lack of data left or right of the recorded period. The trends obtained for these temperature time series are shown in Figure 3. The mean temperature displays a positive trend in the period 1888 - 1970. In the period 1888 - 1938, the temperature rises at the rate of 0.01°C yr^{-1}, tends to remain constant to 1970 and decrease for the following years.

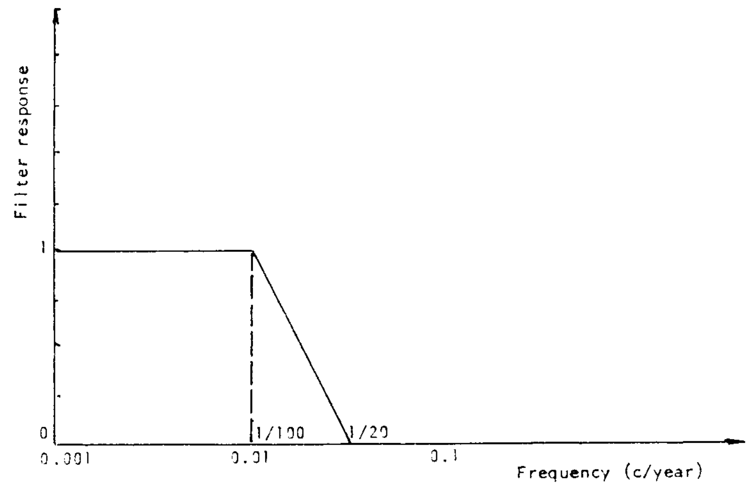

Fig. 4. Frequency response of the low-pass filter used in the data processing.

There is a similar trend in the maximum temperatures which increase until 1929. The maximum temperature remains more or less constant between 1929 and 1970. This is followed by an overall decrease from 1971 to 1987. This latter-day cooling of climate may be partially an artifact caused by end effects of the application of the Ormsby filter itself, since filter end effects are likely to have become a very important influence on all values after 1965. A similar problem arises in the beginning of the series. (Figure 3).

The minimum temperatures show a little different behaviour; they tend to increase even in recent years, while the mean and maximum ones show a decrease. In particular, the minimum temperatures tend to increase as well, after 1920 until 1945. After 1946 they increase at a slight rate until 1987. Similar trend were found to data referring to other European cities, e.g., Paris (Dettwiller, 1978), Rome (Colacino *et al.,* 1983) and Athens (Katsoulis, 1987). The aspect of temperature change in Belgrade shows periods with no definite trends apparent. This may be due normal interannual variability of the weather during these periods when compared to the variability of weather in cities in humid climates of Europe. It is particularly important that the area of Belgrade lies in close proximity to the two great rivers, and large contrast are often absent.

The heat island effect may be said to partially explain the increase in minimum temperature as a long-term variation affecting the local micro-climate. It implies that differences in the maximum and minimum temperature trends may be interpreted as a long-term variation due to the city's growth and the result of increasing urban temperature due to human causes. This effect is stronger in the minimum temperatures than in the maximum and mean ones, since the heat island effect is more intensive during the night than during the day (Oke, 1974; Landsberg, 1981). Minimum urban temperature increase usually explained by connecting the temperatures with the growth of population, a parameter that reflects the size of the city itself. In the case of Belgrade, the correlation analysis was carried out using annual data referring to the growth of population from 1890 to 1981 versus the corresponding minimum temperatures. Regression was carried out using relation of the following type taken from the literature (Garstang, 1975; Landsberg, 1981),

$$T_m = a + b \log P, \qquad (P = \text{population}). \tag{4}$$

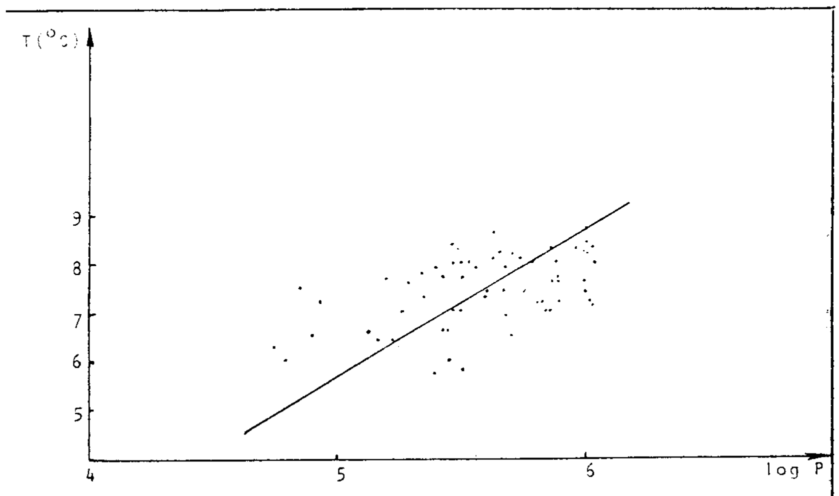

Fig. 5. Regression analysis results obtained for the correlation between minimum temperature sequence and population number following the logarithmic model.

The distribution trend is given in Figure 5, which shows the straight line that fits the data by using the above formula. The minimum temperatures show a tendency to increase even in the recent 30 yr. In the same period the population of the Belgrade city increased from 428 000 (1951) to 1.090 000 (1981). This has led to increased heating activities in the city (more use of central heating, air conditioning, release of energy by industrial activity, etc.), which substantially raise the temperature of air above the city.

5. Concluding remarks

In this paper, we have tried to find whether there is any evidence that reveals change of the climate of Belgrade and also to give some insight into the confidence with which available data can be used to evaluate climatic change. The attempt was made by means of climatological analysis of long-time of temperature (Jones *et al.,* 1982, 1986). Indeed, it is evident that in a city as large as Belgrade, the air temperature is determined not only by natural climatological controls, but it is also influenced by anthropogenic activities, probably by the urban heat island effect. From the above results, the following conclusions are obtained concerning natural and human influences on the temperature:

(1) the mean and mean maximum temperatures show different behaviour patterns than the mean minimum temperature. This can be explained by the fact that the growth of the city and the human activities connected with it have created a well-defined local micro-climate;

(ii) this effect can be quantified, and the Oke formula (Oke, 1974), which links the minimum temperature with the logarithm of the population number is confirmed;

(iii) the analysis of the trend confirms the patterns found by other researchers (Yamamoto and Hoshiai, 1980; Vinnikov *et al.*, 1980) which can be summarized by an increase temperature from 1890 to 1960 and decrease in more recent years.

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