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An urban bias in air temperature fluctuations at the Klementinum, Prague, The Czech Republic

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Abstract

The intensification of an urban heat island, and its influence on the seasonal and annual air temperature measurements of the Prague-Klementinum station, is studied through a comparison with rural stations. Urban warming in the period from 1922 to 1995 was most conspicuous in winter and in spring (0.06°C 10 yr^{-1}), and the smallest and least significant in summer (0.01°C 10 yr^{-1}). Since the 1960s, a stagnation in the development of the urban heat island has appeared. The degree of urban warming prior to 1922 can only be roughly determined because of the lack of a suitable set of homogeneous reference stations. The results of this study are compared with other studies analogous in character.

Keywords: Urban heat island; Air temperature; Prague; Klementinum

1. Introduction

The Prague-Klementinum station (latitude 50°05'N, longitude 14°25'E, altitude 197 m ASL) was established in the vast complex of buildings of the College of St. Clement (shortened in Czech to the "Klementinum"), which was built by the Jesuits in the Old Town of Prague. Given that the continuous measurement of air temperature began there as early as 1 January 1775, this series is among the longest found in Europe and hence it is often used in the analysis of air temperature fluctuation (see e.g. Brázdil and Dobrovolný, 1993), and for the calibration of proxy data from the Czech Republic (Brázdil, 1996). The fact that the station is located in the historical centre of Prague makes itself known through the existence of an urban heat island and its subsequent influence on temperature measurements (see Brázdil, 1993). The study of changes in the Prague temperature series is the objective of the present contribution.

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2. The Prague-Klementinum station and the urban heat island

The first measurements of air temperature at the Prague-Klementinum (further, only Klementinum) were carried out on the fourth floor of the astronomical tower (39 m above the ground). Sometime between 1782 and 1788, the location of the measurements was moved to the southeastern part of the largest courtyard of the block of buildings. The thermometer was located in a metal meteorological screen on the northern side, near the window of a flat on the second floor (11 m above the ground). Since 30 May 1889, it has been permanently installed in the same screen near a window on the first floor (6.5 m above the ground). The position of the thermometer had been changed between the two floors several times before 1889. According to Hlaváč, 1937, these shifts, just as with structural changes in the courtyard (in 1863, 1924 and 1929), have not affected the homogeneity of measurements which "was not impaired by the so-called progressive warming under the influence of the large town".

The measurements of air temperature themselves are affected on the one hand, locally (in essence, the closed space of a courtyard), and on the other hand, by its location (the presence of a large city and the location of

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the station within the historical heavily built-up centre of Prague). Whereas, local conditions can be changed only as the result of building changes in the space of the courtyard, changes in the regional conditions are connected with the gradual development of the town and can be seen in the intensification of the urban heat island (further only UHI). Chronological changes in the value of the UHI can significantly affect the measured air temperature values and thus their projected fluctuation.

3. Data and methods

The determination of the size of the UHI begins with the calculation of temperature differences between the urban station and rural stations in the surroundings. Therefore, a series of mean seasonal and annual air temperatures were collected from 18 stations situated within a maximum of 40 km from the Klementinum and having at least 20 yr of continuous observations in the period between 1921 and 1995 (Fig. 1, Table 1). A continual series of observations during that period also exists from another urban station, Prague-Karlov, situated on the roof of a building at a height of 34 m above the ground. Unlike the Klementinum, however, it is a comparatively well-aerated position with a height of about 80 m above the city centre. All the stations employed, after correcting the errors and supplying missing data, were tested for their relative homogeneity using the bivariate test (Maronna and Yohai, 1978) and the standard

Fig. 1. The geographical distribution of stations in Prague and its surroundings, within 50 km of the Klementinum (1: historically urbanized territory; 2: the Prague agglomeration).

Table 1
Linear trends (°C 10 yr^{-1}) in air temperature differences between the Prague-Klementinum and selected stations in its surroundings between 1921 and 1995

Station	*d*	Period	DJF	MAM	JJA	SON	Year
Prague-Karlov	2	1921–95	**0.052**	**0.067**	**0.029**	**0.044**	**0.051**
Prague-Ruzyně	10	1946–95	**0.089**	**0.083**	0.024	**0.070**	**0.059**
Prague-Kbely	11	1922–37	0.069	0.061	0.099	0.031	0.044
Prague-Kbely	11	1961–95	– 0.003	– 0.011	– 0.015	– 0.039	– 0.034
Průhonice	13	1940–60	0.006	**0.074**	0.056	0.051	**0.132**
Prague-Uhříněves	15	1940–60	0.002	0.127	0.058	**0.147**	**0.122**
Prague-Uhříněves	15	1969–95	– **0.142**	– 0.054	– 0.071	0.023	– **0.061**
Říčany	20	1934–60	0.099	– 0.014	– 0.027	0.011	0.040
Brandýs n. L.	21	1933–95	**0.095**	**0.041**	0.005	**0.044**	**0.040**
Jílové	22	1943–75	**0.108**	**0.140**	**0.075**	**0.154**	**0.110**
Kladno	23	1942–92	**0.129**	**0.065**	0.017	**0.054**	**0.071**
Tišice	24	1954–92	0.055	**0.048**	0.010	0.029	0.048
Štěchovice	26	1930–53	– **0.140**	– 0.039	0.038	– 0.002	– 0.007
Beroun	28	1948–95	**0.069**	**0.095**	– 0.020	**0.051**	0.028
Slaný	29	1940–60	0.039	0.012	0.108	– 0.001	– 0.029
Český Brod, Liblice	32	1932–60	– 0.055	0.022	– 0.057	**0.117**	0.005
Český Brod, Liblice	32	1973–95	– 0.054	0.009	– 0.059	– 0.072	– 0.040
Ondřejov	33	1941–95	**0.121**	**0.073**	**0.041**	**0.056**	**0.076**
Lysá n. L.	33	1941–83	**0.121**	**0.047**	0.007	**0.091**	**0.062**
Hostomice	39	1930–79	**0.151**	**0.083**	0.015	**0.121**	**0.093**
Roudnice n. L.	40	1939–60	**0.137**	– 0.023	– 0.053	**0.094**	0.008
Average series	23	1922–95	**0.063**	**0.061**	0.009	**0.049**	**0.047**

Note: Bold – significance level $\alpha = 0.10$, bold underlined $\alpha = 0.05$. Stations are ordered according to distance (*d* in km) from the Prague-Klementinum (DJF – winter, MAM – spring, JJA – summer, SON – autumn).

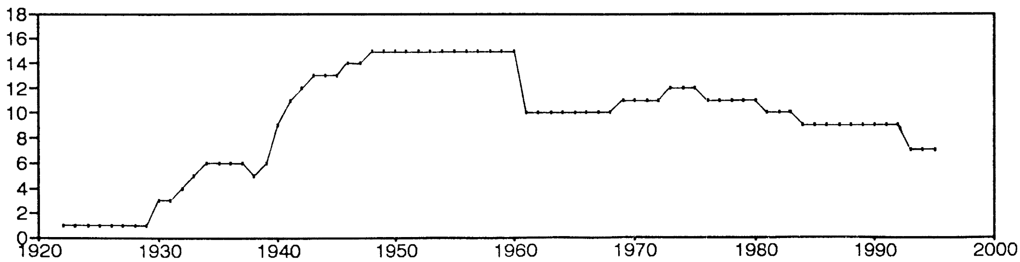

Fig. 2. The number of stations in the surroundings of Prague-Klementinum employed in individual years for the calculation of the average series.

normal homogeneity test (Alexandersson, 1995). Series with significant non-homogeneity, at the level of significance $\alpha = 0.05$, were subsequently homogenized, the metadata of the individual stations being taken into consideration.

Of the 17 homogenized seasonal and annual temperature series (excluding Prague-Karlov), their anomalies were calculated (reference period 1951–1960), from which the corresponding average series for the surroundings of Prague were determined. Temperature anomalies were used with respect to the variable number of stations available for individual years (Fig. 2). Before 1941, the number of stations available for calculation was rather small (in 1922–1929, only data from the airport at Prague-Kbely was available), and a further decline in the number of stations has taken place since the early 1960s.

For the quantification of the UHI of Prague for the period before 1922, the homogeneous series of the German station Potsdam (Lehmann and Kalb, 1993), the Czech station Milešovka (Štekl and Zacharov, 1993) and the Austrian stations Kremsmünster and Vienna-Hohe Warte (Böhm, 1992) were used.

In the next phase of processing, seasonal and annual series of temperature differences between the Klementinum and the homogenized stations from the surroundings were calculated, the same was done between the Klementinum and the average series. For these series, the linear trend was calculated, the significance of which was tested using the t-test, with the levels of significance at $\alpha = 0.10$ and 0.05.

4. Results of the analysis

Linear trends in the seasonal and annual temperature differences between the Klementinum and the stations employed for the period 1921–1995 are given in Table 1 and shown in Fig. 3. Generally, positive and statistically significant trends documenting additional warming of the Klementinum, in comparison with the other stations used, prevail. From time to time, negative trends also appear, as a rule tied to stations with shorter periods of observation during the three-to-four decades prior to 1995. Of interest are statistically significant trends in the differences with Prague-Karlov and Prague-Ruzyně. In the case of the former station, their smaller urban effect follows from the position of the station (see Section 3). The station Prague-Ruzyně is situated at the airport, thus being beyond any effect of the town. Of greater significance than this, in comparison with the individual stations, are those linear trends in differences between the Klementinum and the averaged series of 17 stations from its environs, in which possible undiscovered non-homogeneities at the individual stations have been minimized. This comparison documents additional and, with the exception of summer, a statistically significant urban warming at the Klementinum in each of the seasons and over the year as a whole. This warming is most conspicuous and significant in winter and in spring (0.06°C 10 yr^{-1}), comparable in autumn and over the whole year (0.05°C 10 yr^{-1}), and the smallest and least significant in summer (0.01°C 10 yr^{-1}).

In Table 2, linear trends in the temperature differences between the Klementinum and the four selected central European series with measurements before 1922 are presented. These results are, to a greater extent, affected by the local character of the given station and its distance from Prague. In comparison with Potsdam (without an urban effect) and Milešovka (the mountain station), the warming of the Prague station is significant in all seasons of the year as well as over the whole year. In comparison with Vienna, the Prague-Klementinum station warms to a statistically significant degree only in spring and over the whole year. In the remaining seasons, the linear trends in the differences between the two stations are not statistically significant, the same holds true in the comparison of Prague with Kremsmünster. From this, it can be judged that the two Austrian stations are also partly

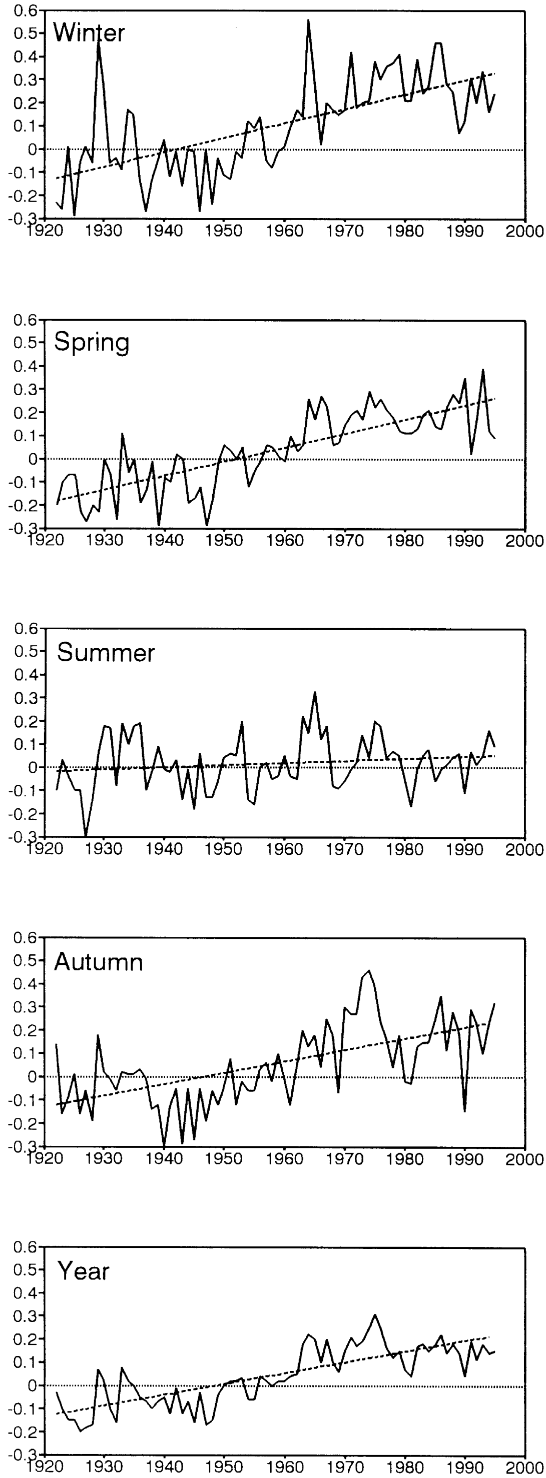

Fig. 3. The variation of differences in the mean air temperature Prague-Klementinum, less the averaged series (°C) in the period between 1922 and 1995, with the linear trend.

Table 2
Linear trends (°C 10 yr^{-1}) in air temperature differences between the Prague-Klementinum and selected central European stations

Station	d	H	Period	DJF	MAM	JJA	SON	Year
Potsdam	277	81	1893–95	**0.102**	**0.083**	**0.042**	**0.038**	**0.063**
Milešovka	69	833	1905–93	**0.093**	**0.089**	**0.068**	**0.067**	**0.077**
Kremsmuenster	232	388	1876–95	– 0.015	0.014	– 0.018	– 0.006	– 0.007
Vienna – Hohe Warte	257	202	1876–95	0.004	**0.044**	0.011	0.012	**0.016**

Note: Bold – $\alpha = 0.10$, bold underlined – $\alpha = 0.05$, d – distance from the Prague-Klementinum in km, H – altitude in m, DJF – winter, MAM – spring, JJA – summer, SON – autumn.

affected by the intensification of the UHI. On the other hand, with respect to their greater distance from Prague, other effects can also make themselves felt.

The intensification of the Prague UHI is also evident in the daily temperature extremes (Brázdil et al., 1994). Thus, in terms of the annual means of the daily maxima, the upward trend at the Klementinum between 1961 and 1990 was 0.34°C 10 yr^{-1} (the significance for $\alpha = 0.05$) as opposed to 0.19°C 10 yr^{-1} in the Czech Republic (the mean series from 24 stations at a height above sea level of between 158 and 573 m). The situation was also analogous for the annual means of the daily minima with values of 0.41°C 10 yr^{-1} ($\alpha = 0.05$) and 0.24°C 10 yr^{-1} ($\alpha = 0.10$), respectively.

5. Discussion and conclusions

In a previous paper by Brázdil (1993), the warming at the Klementinum due to the intensification of the UHI was estimated to be 0.07–0.08°C 10 yr^{-1} from the beginning of the century up to about 1940, increasing afterwards to about 0.1°C 10 yr^{-1}. In this paper, the values of warming are somewhat lower. Higher values of warming following from the comparison with Milešovka can be explained by the fact that at mountain stations, the linear upward trend of air temperature in our century is lower than at stations at lower elevations (Brázdil et al., 1996).

The information obtained about the changes in the UHI at the Klementinum correlate to different degrees with analogous papers, this being connected with the heterogeneity of factors affecting the formation of the UHI and the different developments of the towns. Thus, for Leipzig in Germany, in comparison with Schwerin, the temperature rise from the beginning of the century to the early 1970s was larger by 0.6°C (Börngen and Dobierzin, 1976). Helbig (1988) found, on the basis of the comparison of a station in central Berlin and one in Potsdam, an increase of a mere 0.03°C 10 yr^{-1} between 1893 and 1980. An analogous value, 0.02°C 10 yr^{-1}, is also given for Lisbon in Portugal (Antunes et al., 1996). For Krakow in Poland, Kozuchowski et al. (1994) determined the warming trend to be 0.13°C 10 yr^{-1} from 1951 to 1990. Chernavskaya (1985), using data from Moscow, St. Petersburg, Nizhni Novgorod and Ekaterinburg in Russia, gives a warming by 0.18–0.24°C 10 yr^{-1} in January and by 0.08–0.12°C 10 yr^{-1} in July and presents a more conspicuous intensification of warming since the 1940s (e.g. in January by 0.3–0.4°C 10 yr^{-1}). A higher value of warming, 0.34°C 10 yr^{-1} from 1952 to 1976, was found for Vienna in Austria by Böhm (1979). Kukla et al. (1986) estimated the intensification of the UHI in North America between 1941 and 1980 to be on the average 0.12°C per decade and gives a list of results from other papers with the warming rate ranging from 0.0 to 0.42°C 10 yr^{-1}.

The intensification of the UHI is usually correlated with an increase in the size of the urban population, the extension of the urban built-up areas and the increasing consumption of energy. Thus, Böhm (1979) states, in clarifying the intensification of the UHI in Vienna, that the number of inhabitants between 1952 and 1976 remained practically unchanged, the built-up area increased by 8%, but overall energy consumption increased by 150%. A depiction of the growth of the population of Prague is given in Fig. 4, from which a conspicuous deceleration in population growth in the last 50–60 yr is clearly perceptible. Whereas the number of inhabitants in the historical centre and the inner city has decreased, in the outer city and the periphery, it has increased (Hrůza, 1992). The consumption of energy, however, increased conspicuously only between 1975 and 1987, the terminal energy consumption increased by 25.5% (Brázdil, 1993). These factors, together with the expansion of the built-up area (for example, the increase in the built-area reached about 85% of the inner city between 1921 and 1970 – Hovorka, 1975), may possibly be considered to be the main reasons for the intensification of the UHI.

Additional warming of urban stations can markedly decrease the real values of the observed temperature trends. Thus, in the case of the Klementinum between 1922 and 1995, it is necessary to reduce the observed linear trends resulting from the UHI by 21% for winter,

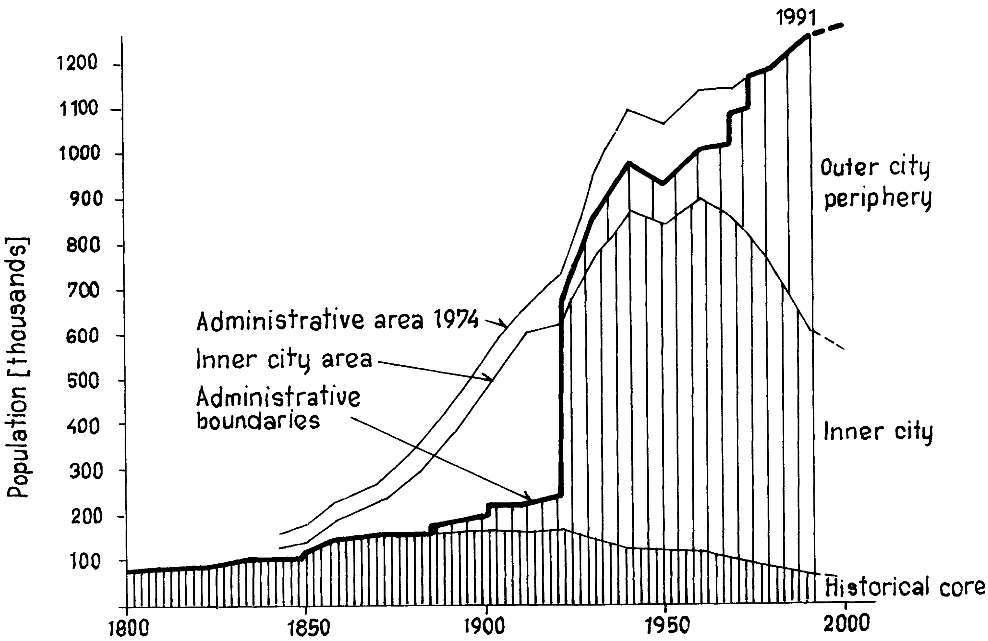

Fig. 4. Growth and distribution of the population of Prague (adapted according to Hrůza, 1992).

by 27% for the year as a whole, by 31% for spring and by as much as 78% in the autumn, but by only 7% for summer. The relatively greatest reduction in the values of the linear trend in autumn is due to its lower value (0.63°C 100 yr^{-1}) in comparison with winter (3.05°C 100 yr^{-1}) and spring (1.98°C 100 yr^{-1}). The variation of the mean annual air temperatures at the Prague-Klementinum (corrected for the intensification of the UHI) is, in comparison with the measured values of the period of 1922–1995, presented in Fig. 5. Hansen and Lebedeff (1987), in assessing global trends, have found an urban bias effect over the United States of between 0.3 and 0.4°C over the twentieth century, which is even larger than the overall trend in the United States. In the global temperature series for the northern hemisphere, the warming urban effect should not exceed 0.1°C (Jones et al., 1989).

On the other hand, it is, however, assumed that in a period of global warming, the intensity of the UHI should decrease in connection with a more frequent, unstable temperature stratification and the subsequent dissipation of urban heat. Thus, a reduction in the UHI is noted in the analyses for Buenos Aires, four cities in Australia and 31 in the US (Camilloni and Barros, 1996). Nkemdirim (1996) presents a decrease in urban–rural differences for Calgary between 1960 and 1990, which he places in connection with a drop in energy consumption. As stated in Section 4, an analogous decrease in differences has also been registered since the 1960s at three stations in the surroundings of the Klementinum (see Table 1). In addition, from the variation of differences between the Prague-Klementinum and the averaged series (Fig. 3), it follows that since the first half of the 1960s, the differences have fluctuated practically at a more or less constant level and/or have decreased (summer). In the end, this is also confirmed by a statistically significant ($\alpha = 0.05$) change points in the mean for the early 1960s (1963 for winter, 1962 for spring, 1961 for autumn and year).

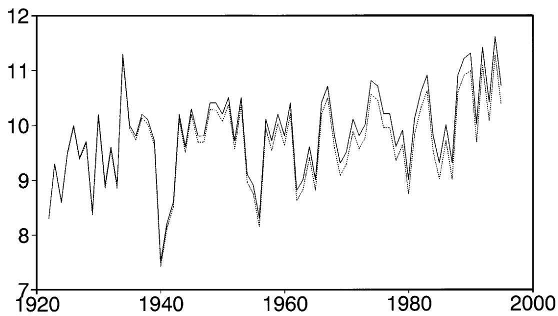

Fig. 5. The variation of mean annual air temperatures (°C) at the Prague-Klementinum in the period 1922–1995: solid line – measured values, dotted line – values reduced by the intensification of the urban heat island according to the linear trend in 1922–1995.

This analysis has demonstrated the fact that the use of the Klementinum series for the study of air temperature fluctuation is misleading, if no correction for the intensification of the UHI is made in the measured temperatures. A certain rate of uncertainty in the quantification of time changes in the UHI is connected with variability in the choice of the stations employed, the quality of their measurements and the homogenization made. The estimate of the development of the UHI in the 19th century remains, for the time being, a task for the future. Successfully carrying this out is bound to a quality homogenization of additional long-term Czech temperature series, going as far back as to the 19th century.

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