ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tom. 36-37, 2003, 93-100.

CLASSIFICATION OF THE URBAN HEAT ISLAND PATTERNS

Z. SÜMEGHY and J. UNGER

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: sumeghy@geo.u-szeged.hu

Összefoglalás – A vizsgált település, a 160.000 lakosú Szeged, méreténél, illetve hegységektől és nagy vízfelületektől távol eső síksági fekvése miatt kiválóan alkalmas a városi hősziget (UHI) kutatására. A hőmérsékleti adatokat egy előzetesen kijelölt gridhálózat mentén mobil mérésekkel gyűjtöttük különböző időjárási viszonyok mellett 2002 áprilisa és 2003 márciusa között, minden esetben az UHI maximális kifejlődésének várható időpontjában. Célunk volt: (i) a standard Kriging eljárás alkalmazásával izoterma térképek szerkesztése, amelyek a szezonális átlagos UHI intenzitás térbeli eloszlását mutatják be, és (ii) az egyedi hőmérsékleti mintázatok generalizált típusokba sorolása normalizálás és kereszt-korreláció felhasználásával.
A tanulmányozott időszakban az UHI intenzitási mezők térbeli eloszlása koncentrikus alakzatot mutatott, néhány helyi szabálytalansággal. Az UHI mintázat korrelációs együtthatós osztályozásának eredményeként, alakzat szerint, nyolcféle típust különböztethetünk meg. A szabályos koncentrikus mintázathoz képest a formák különböző jellegű eltolódásai valószínűleg a mérésekkor uralkodó eltérő szélirányokkal állnak kapcsolatban.

Abstract – The studied city (Szeged, Hungary) is located on a low and flat flood plain with a population of 160,000. Data were collected by mobile measurements in a grid network under different weather conditions between April 2002 and March 2003 in the time of the maximum development of the urban heat island (UHI). Tasks include: (i) Construction of isotherm maps to show the seasonal mean spatial distributions of the UHI intensity applying the standard Kriging procedure. (ii) Classification of individual temperature patterns into generalized types using normalization and cross-correlation.
In the studied periods the spatial distribution of UHI intensity fields had a concentric shape with some local irregularities. As a result of the UHI pattern classification using correlation coefficients eight types of the form can be distinguished. The shifts of the forms in comparison with the regular centralized pattern are, presumably, in connection with the prevailing wind directions.

Key words: UHI, seasonal patterns, classification of patterns, cross-correlation, Szeged, Hungary

INTRODUCTION

Urbanization modifies materials, structure and energy-balance of the surface and composition of the atmosphere compared to the surrounding natural environments. These artificial alterations determine a distinguished local climate in the cities, which is called as urban climate. The climate modification effect of urbanization is most obvious for the temperature excess (urban heat island – UHI), which is characterized by the the UHI intensity (namely ΔT, the temperature difference between urban and rural areas). Generally, this intensity has a diurnal cycle with a strongest development at 3-5 hours after sunset.

Counting all weather conditions except rain, the objective of the study is to investigate the air temperature distribution inside the city a few hours after sunset, when the UHI effect is most pronounced. In order to achieve this aim, we construct isotherm maps to show the spatial distributions of the UHI intensity and classify these temperature patterns into generalized types.

STUDY AREA AND METHODS

General

Szeged is located in the south-eastern part of Hungary (46°N, 20°E) at 79 m above sea level on a flat plain (*Fig. 1*). The River Tisza passes through the city, otherwise, there are no large water bodies nearby. The river is relatively narrow and according to earlier investigations its influence is negligible (*Unger et al.,* 2001). These environmental circumstances make Szeged a favourable place for studying of an almost undisturbed urban climate.

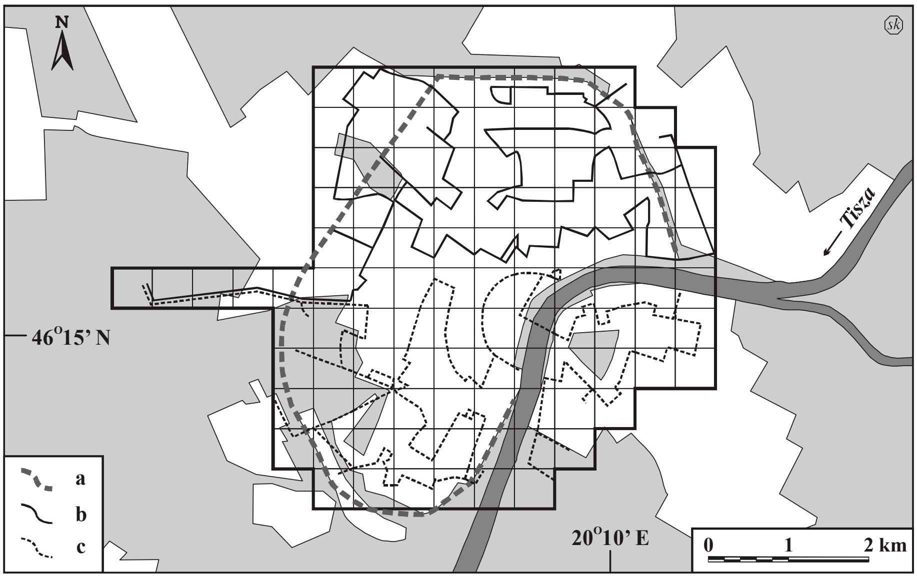

Fig. 1 Division of the study area into 0.5 km x 0.5 km grid cells, (a) circle dike and measurement routes in the (b) northern and (c) southern sectors. The urban areas are marked by white.

In the city, within the administration district of 281 km^2, the number of inhabitants is 160,000. The region is in Köppen's climatic region Cf (temperate warm climate with a fairly uniform annual distribution of precipitation). The annual mean temperature is 10.4ºC and the annual mean precipitation amount is 497 mm.

Grid network and temperature (maximum UHI intensity)

The area of investigation (inner part of the administration district) was divided into two sectors and subdivided further into 0.5 km x 0.5 km cells (*Fig. 1*). It consists of 107 cells covering the urban and suburban parts of Szeged (26.75 km^2). The outlying parts of the city, characterized by village and rural features, are not included in the network except for four cells on the western side of the area. These four cells are necessary to determine the temperature contrast between urban and rural areas.

In order to collect temperature data for every cell, mobile measurements were taken on fixed return routes during the period of April 2002 – March 2003, altogether 35 times (*Fig. 1*). In case of surface and near-surface air UHI investigations, the moving observation with different vehicles (car, tram, helicopter, airplane, satellite) is a common process (e.g. *Conrads and van der Hage*, 1971; *Oke and Fuggle*, 1972; *Voogt and Oke*, 1997; *Klysik and Fortuniak*, 1999). We used one car by sectors at the same time. The frequency of car traverses (one measurement per 10 days) provided sufficient information under different weather conditions, except for rain. *Table 1* and *Table 2* summarize the details of measurements.

Table 1 Monthly and seasonal numbers of mobile measurements in Szeged (April 2002 – March 2003)

M	A	M	J	J	A	S	O	N	D	J	F
3	3	3	3	3	3	3	3	3	2	1	5
Spring			**Summer**			**Autumn**			**Winter**		
9			9			9			8		
	non-heating season							**heating season**			
	18							17			

Return routes were needed to make time-based corrections and the measurements took about 3 hours. Readings were obtained using a radiation-shielded resistance sensor connected to a data logger for digital sampling. Data were collected every 10 s, so at a car speed of 20-30 km h^{-1} the distance between measuring points was 55-83 m. The sensors were mounted 0.60 m in front of the cars at 1.45 m above ground to avoid engine and exhaust heat. The speed provided adequate ventilation for the sensors to measure the ambient air temperature. The logged values at forced stops were rejected from the data set.

Having averaged the 15-20 measurement values by cells, time adjustments to a reference time (namely the likely time of the occurrence of the strongest UHI in the diurnal course – maximum UHI) were applied assuming linear air temperature change with time. It was 4 hours after sunset, a value based on earlier measurements. Consequently, we can assign one temperature value to every cell (centerpoint) in the sectors in a given measuring night. ΔT values were determined by cells referring to the temperature of the westernmost cell of the study area, which was regarded as a rural cell because of its location outside of the city. The 107 points (the above mentioned centerpoints) covering the urban parts of Szeged provide an appropriate basis to interpolate isolines applying the standard Kriging procedure.

Mean seasonal distributions and classification of the UHI patterns

Two half years can be distinguished from the point of view of city dwellers: the non-heating (from April 16th until October 15th) and the heating (from October 16th until April 15th) seasons. From the 35 measuring nights, according to this time division, there are 18 and 17 in the non-heating and heating seasons, respectively. The mean seasonal and annual spatial distributions were determined by averaging the absolute UHI intensities by cells.

Table 2 Survey of mobile measurements in the study area of Szeged in the period of April 1999 – March 2003 (CET – Central European Time)

No.	Date	Measuring period		Reference time (CET)	max. ΔT (ºC)
		Northern sector	*Southern sector*		
1	05. 04. 2002	2h 54m	3h 00m	22.15	0.818
2	15. 04. 2002	2h 51m	3h 00m	22.15	2.567
3	22. 04. 2002	3h 01m	3h 08m	22.45	3.214
4	06. 05. 2002	2h 53m	2h 58m	23.00	2.187
5	15. 05. 2002	2h 53m	3h 04m	23.15	4.843
6	23. 05. 2002	2h 52m	2h 59m	23.30	1.178
7	04. 06. 2002	2h 58m	3h 07m	23.30	4.069
8	13. 06. 2002	2h 57m	3h 02m	23.45	4.753
9	26. 06. 2002	2h 47m	2h 57m	23.45	4.259
10	05. 07. 2002	2h 48m	2h 50m	23.45	4.794
11	15. 07. 2002	2h 51m	2h 57m	23.30	3.477
12	24. 07. 2002	2h 48m	3h 03m	23.30	1.180
13	06. 08. 2002	2h 54m	2h 56m	23.15	0.972
14	21. 08. 2002	2h 49m	2h 57m	22.45	3.832
15	27. 08. 2002	2h 48m	2h 49m	22.30	2.000
16	02. 09. 2002	2h 49m	3h 00m	22.30	1.004
17	18. 09. 2002	2h 51m	2h 57m	22.00	4.467
18	30. 09. 2002	2h 57m	2h 55m	21.30	1.434
19	07. 10. 2002	2h 57m	3h 08m	21.15	3.111
20	14. 10. 2002	3h 03m	3h 05m	21.00	1.833
21	28. 10. 2002	3h 00m	3h 11m	20.30	1.107
22	12. 11. 2002	3h 00m	3h 12m	20.15	2.615
23	18. 11. 2002	2h 57m	3h 01m	20.00	3.207
24	27. 11. 2002	2h 59m	3h 00m	20.00	2.756
25	12. 12. 2002	3h 00m	3h 05m	20.00	0.346
26	20. 12. 2002	3h 06m	3h 06m	20.00	2.403
27	27. 01. 2003	3h 05m	3h 10m	20.30	1.060
28	02. 02. 2003	2h 58m	3h 16m	20.45	4.423
29	17. 02. 2003	3h 01m	3h 14m	21.15	3.938
30	18. 02. 2003	3h 01m	3h 07m	21.15	5.052
31	24. 02. 2003	2h 59m	3h 02m	21.15	1.600
32	26. 02. 2003	3h 04m	3h 05m	21.30	5.055
33	05. 03. 2003	2h 59m	3h 04m	21.30	2.616
34	24. 03. 2003	2h 55m	3h 03m	22.00	6.815
35	25. 03. 2003	2h 57m	3h 03m	22.00	5.476

The first step for the grouping the UHI patterns by the forms was the normalization of the ΔT values of each pattern. In course of the normalization the absolute intensities by cells were divided by the absolute value of the cell which had the maximum intensity at the given night. This process eliminates the alterations caused by the differences in the UHI magnitude. Then, cross-correlation was applied for the normalized temperature patterns (107 ΔT values) of the 35 measuring nights. It means altogether 595 relationships between the different patterns. For practical purposes, the coefficients can be gather in a cross-correlation matrix (*Montavez et al.,* 2000). In our case the correlation coefficient is significant at the 99% of confidence level if it is larger than 0.25 (n = 107).

The classification is based on the next simple common feature: those patterns are in a class (or type) which are in the above mentioned significant correlation with each other pattern in the class.

RESULTS AND DISCUSSION

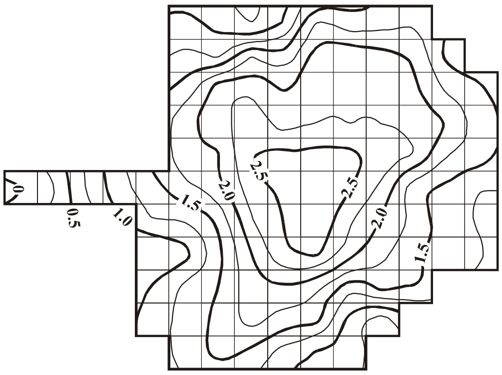

Fig. 2 Spatial distribution of the mean max. UHI intensity (ºC) during the investigated one-year period in Szeged

In both seasons and in the one-year period the shapes of the UHI patterns are almost concentric and the temperature values are increasing from the outskirts towards the inner areas. A large deviation from this shape occurs in the north-eastern part of the city, where the isotherms stretch towards the suburbs. This can be explained by the effect of a large housing estate with high concrete buildings and with high built-up ratio (*Bottyán and Unger*, 2003). In the whole investigated period the greatest mean intensity (2.72ºC) is found in the central cell. The area of considerable differences (ΔT of higher than 2ºC) covers about 30% of the total area (*Fig. 2*).

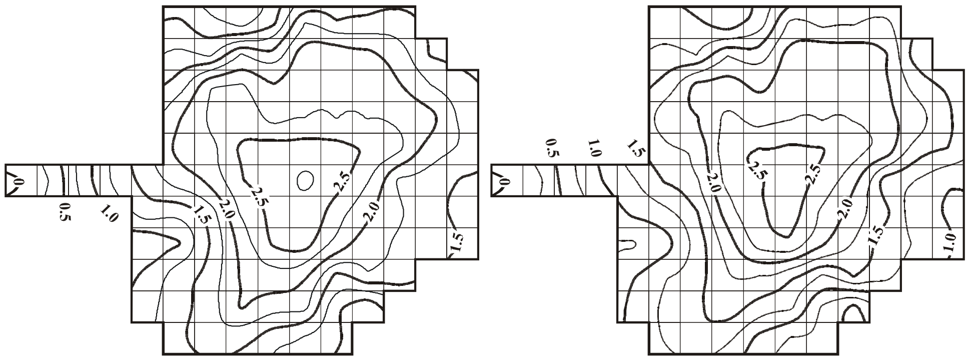

Fig. 3 Spatial distribution of the mean max. UHI intensity (ºC) during (a) the non-heating season and (b) the heating season in Szeged

In the half-year seasons the structure of the UHI is very similar to the one-year period, only the highest values differ slightly. In the non-heating season the ΔT is a bit larger (2.79ºC), while in the heating season it is a bit smaller (2.63ºC), than in the one-year period (*Fig. 3*).

According to the classification of the individual UHI patterns using correlation values, eight types of the form (marked by **A**, **B**, ...) can be distinguished. *Table 3* contains

Table 3 Names, members and ranges of the measured maximum intensities (ºC) of UHI pattern types

Type	Name	Members	ΔT range
A	centralized	5, 9, 12, 15, 23, 33	0.35 – 5.48
B	shifted to NW	13, 18, 20, 21, 22, 31	1.83 – 3.21
C	shifted to N-NE	4, 6, 11, 24, 25	0.97 – 4.75
D	shifted to E-SE	1, 27, 28, 35	2.57 – 5.05
E	shifted to E-NE	3, 10, 17, 19	1.11 – 4.84
F	shifted to W-SW	2, 7, 29	1.60 – 4.26
G	shifted to S	14, 16, 34	0.82 – 1.43
H	miscellaneous	8, 26, 30, 32	4.42 – 6.81

the members (marked by the numbers of measurements, see *Table 2*) and the ranges of the measured maximum intensities by types. In comparison with the regular, centralized pattern (**A**), the irregularities (or rather shifts) in the forms are reflected in the names of the types. These shifts can be, presumably, explained by the prevailing wind directions at the given measuring nights, but the exact confirmation of this relationship needs further data collection and examination. Example normalized patterns of each distinguished types (except of the miscellaneous type **H**) are exhibited in *Fig. 4*

.

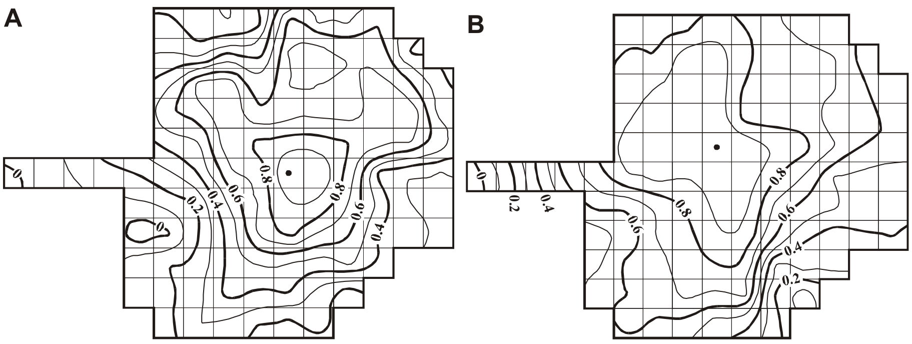

Fig. 4 Example patterns by types and their dates in Szeged. The cells with the highest value are marked by points. **A** (centralized) – 18. 09. 2002, **B** (shifted to NW) – 27. 08. 2002

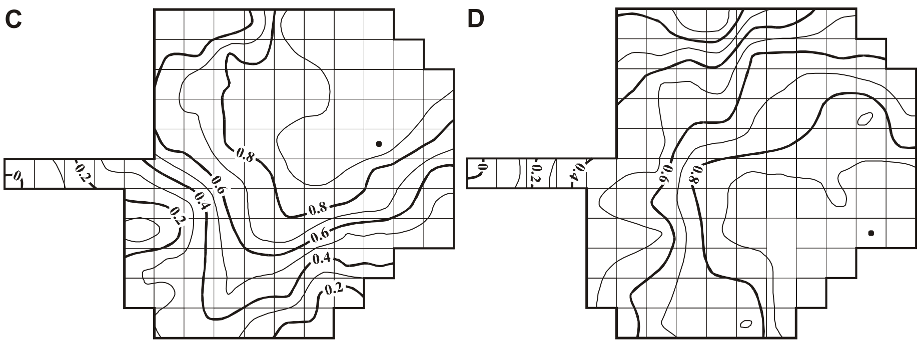

Fig. 4 (continued) **C** (shifted to N-NE) – 13. 06. 2002, **D** (shifted to E-SE) – 18. 02. 2003

E F

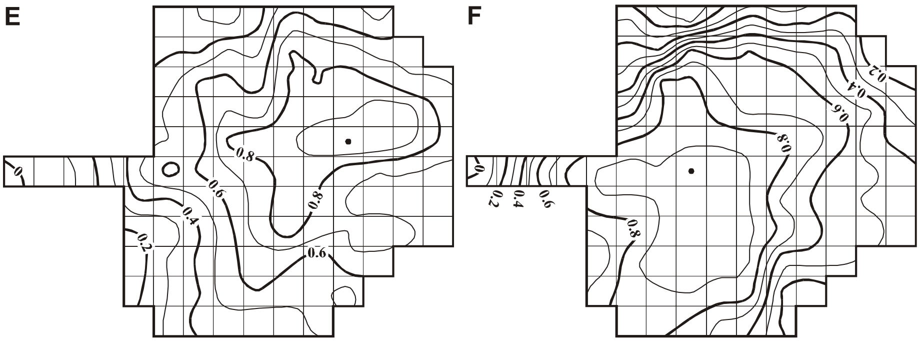

Fig. 4 (continued) **E** (shifted to E-NE) – 24. 07. 2002, **F** (shifted to W-SW) – 26. 06. 2002

G

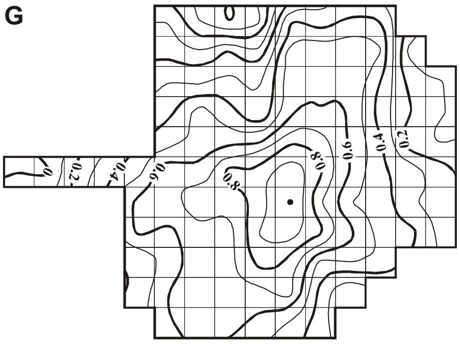

Fig. 4 (continued) **G** (shifted to S) – 05. 04. 2002

CONCLUSIONS

The following conclusions are reached from the analysis presented:

(i) The spatial patterns of the mean UHI intensity have almost concentric shapes. The anomalies in the regularity are caused by the alterations in the urban surface features.

(ii) The normalization of the intensities gave us a useful tool for the comparison and classification of the individual UHI patterns. Eight types of the ΔT pattern can be distinguished. The shifts in the forms are, with a large probability, in connection with the prevailing wind directions.

Acknowledgements – This research was supported by the grant of the Hungarian Scientific Research Fund (OTKA T/034161). The work of the second author was also supported by the Széchenyi István Scholarship of the Ministry of Education (SZÖ 84/2002). The cross-correlation was calculated by Z. Bottyán.

REFERENCES

Bottyán, Z. and Unger, J., 2003: A multiple linear statistical model for estimating mean maximum urban heat island. *Theor. Appl. Climatol. 75*, 233-243.

Conrads, L.A. and van der Hage, J.C.H., 1971: A new method of air-temperature measurement in urban climatological studies. *Atmos. Environ. 5*, 629-635.

Klysik, K. and Fortuniak, K., 1999: Temporal and spatial characteristics of the urban heat island of Lódz, Poland. *Atmos. Environ. 33*, 3885-3895.

Montavez, J.P., Rodriguez, A. and Jimenez, J.I., 2000: A study of urban heat island of Granada. *Int. J. Climatol. 20*, 899-911.

Oke, T.R. and Fuggle, R.F., 1972: Comparison of urban/rural counter and net radiation at night. *Bound. Lay. Meteorol. 2*, 290-308.

Unger, J., Sümeghy, Z., Gulyás, A., Bottyán, Z. and Mucsi, L., 2001: Land-use and meteorological aspects of the urban heat island. *Meteorol. Applications 8*, 189-194.
Voogt, J.A. and Oke, T.R., 1997: Complete urban surface temperatures. *J. Appl. Meteorol. 36*, 1117-1132.