DOI: 10.15201/hungeobull.65.2.8 Hungarian Geographical Bulletin 65 2016 (2) 181–193.

Projection of intra-urban modification of night-time climate indices during the 21st century

Nóra SKARBIT and Tamás GÁL[1]

Abstract

The present paper evaluates the alteration of certain night-time climate indices namely warm nights ($T_{min} \geq 17$ °C) and tropical nights ($T_{min} \geq 20$ °C) during the 21st century in the city of Szeged. This examination was performed within the framework of a project founded by International Visegrad Fund, where the change of more climate indices were examined in several Central European cities. In this study the MUKLIMO_3 microclimatic model was used, which ensured the modelling of the local scale processes in the examined area. In the model for the land use we applied the Local Climate Zone (LCZ) system. In order to analyze longer periods the cuboid method was applied, which is a dynamical-statistical downscaling technique. We calculated the indices for 1981–2010 based on measurements and for 2021–2050 and 2071–2100 from the EURO-CORDEX datasets. In this study we present the results of Representative Concentration Pathways (RCP) scenarios namely RCP 4.5 and RCP 8.5. Our results show that highest values appear in the city centre and the number of the days clearly increases in the 21st century especially according to scenario RCP 8.5. The values depend on the built-up types and there are more days towards to the densely built-up LCZs. Moreover, considering the relative changes of the zones, larger values appear in sparsely built-up zones and natural surfaces.

Keywords: climate indices, Szeged, MUKLIMO_3, Local Climate Zones, EURO-CORDEX

Introduction

By the end of the 21st century the global mean temperature increase likely exceeds 1.5 °C compare to period 1850–1900 (Stocker, T.F. *et al.* 2013). Global climate change affects the environment at regional and local scale as well. Beside the global problems caused by this phenomenon the regional or local consequences are neither negligible. The rate of the urban population continuously increases thus more and more people live in urbanized area. Nowadays, half of the human population is affected by the unfavourable conditions of the city life. The most important climate impacts are air pollution, increased heat load and thermal stress in cities.

In case of summer heat waves, the increased nocturnal temperature might be very stressful, because of the lack of night-time recreation is harmful for the human well-being and health. It raises the question: what awaits us in the future if it is already a huge problem. Furthermore, it is also an important question how the temperature change varies according to the different built-up types. The crucial question is how possible to mitigate climate change at local scale using urban planning actions and which built-up types are preferable? Using the Local Climate Zone (LCZ) system developed by Stewart, I.D. and Oke, T.R. (2012) it is possible to carry out appropriate assessments and modelling. Furthermore, the results may be simple enough to apply or adapt globally in the frame of urban planning.

This study is a part of an international cooperation concentrating on five Central European cities aiming to predict the change

---

[1] Department of Climatology and Landscape Ecology, University of Szeged, H-6722 Szeged, Egyetem u. 2. E-mails: skarbitn@geo.u-szeged.hu, tgal@geo.u-szeged.hu

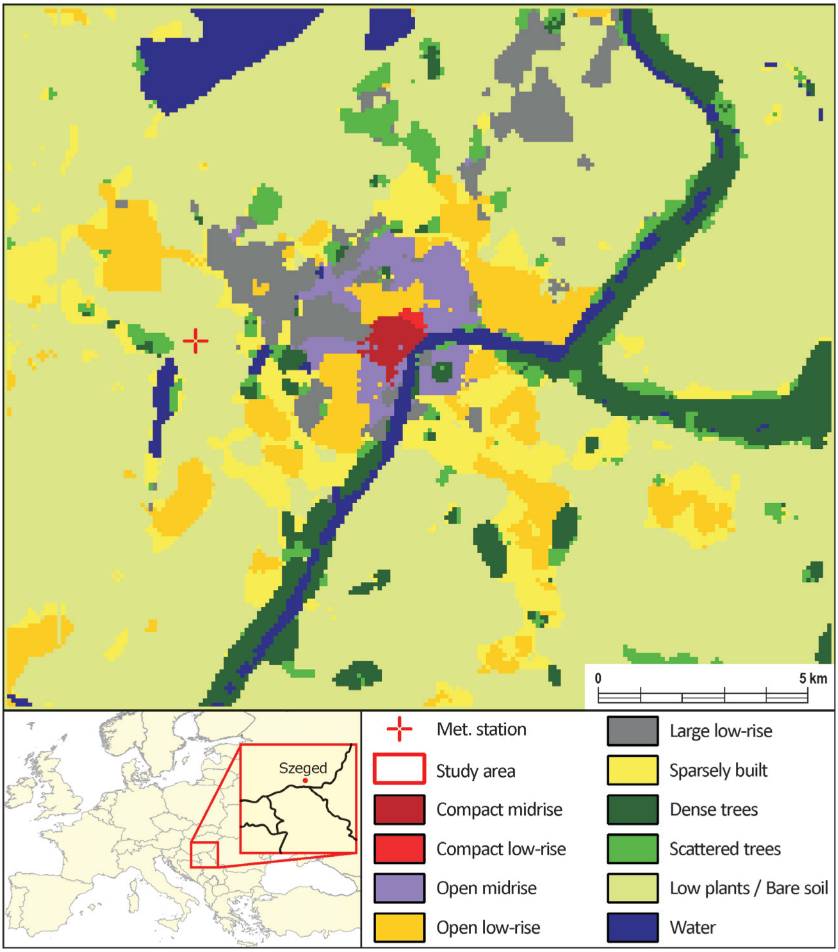


Fig. 1. Study area and the Local Climate Zones in Szeged

of several climate indices in this century (Bokva, A. *et al.* 2015). In case of urban areas, the nocturnal thermal features are the most important therefore we present those indices which characterize the night-time conditions. The indices using daily minimal temperature are appropriate to describe the nocturnal urban-rural thermal differences, thus we examined the average number of warm nights ($T_{min} \geq 17$ °C) and tropical nights ($T_{min} \geq 20$ °C) (Früh, B. *et al.* 2011b).

The aim of this study is to present the change of the number of warm and tropical nights during the 21st century. The spatial pattern of these climate indices was evaluated in the examined area in 1981–2010 as a reference period and the future deviation from this period. This evaluation is extended by the average values for each Local Climate Zone. Furthermore, inter-zone comparisons were carried out based on relative changes from the reference period.

Study area

Szeged is located in the Carpathian Basin in Central Europe *(Figure 1).* It is a medium-sized city in the south-eastern part of Hungary. According to Köppen climate classification system the climate of Szeged is moderately warm with rather uniform annual distribution of precipitation (Cfb) (Kottek, M. *et al.* 2006). The population of the city is approximately 170,000. The average altitude is 80 m and the city is located on a nearly flat terrain. The urbanized area covers approximately 40 km^2 of the city. River Tisza divides the city into two parts and the road network has a regular avenue-boulevard structure. The structure of the city has few characteristic districts: a densely built centre, blocks of flats in the northern part, family houses in the outskirts and warehouses mostly in western part (Unger, J. *et al.* 2001).

Applied data and methods

Local climate zones

In the modelling process we applied the Local Climate Zone (LCZ) classification (Stewart, I.D. and Oke, T.R. 2012) as the basis of land use/land cover data. Originally it was designed for the classification of urban measurement sites, but several different applications are possible. One of the most important opportunities is to use this system as an input data for urban climate modelling to represent better the urban landforms. The application of this system is advantageous because the classification is based on the thermal characteristics of the urban and rural surfaces. Furthermore, it can be connected to the urban heat island phenomenon, which is the most important modification in the urban areas. Nowadays several LCZ mapping methods are known (Lelovics, E. *et al.* 2014; Bechtel, B. *et al.* 2015; Lehnert, M. *et al.* 2015).

In this study, we used Bechtel-method, which is a simple method for LCZ mapping. This method applies free-access satellite imagines and open-source software. For this method two software programs are necessary (Google Earth and SAGA-GIS) and it applies Landsat satellite images as input (Bechtel, B. *et al.* 2015). *Figure 1* presents the obtained LCZs for Szeged. It can be seen that four LCZ classes are absent in Szeged: LCZ 1 (compact high-rise), LCZ 4 (open high-rise), LCZ 7 (lightweight low-rise) and LCZ 10 (heavy industry). Compact midrise (LCZ 2) and compact low-rise (LCZ 3) are located in the centre of the city. Open midrise (LCZ 5) is located near to the city centre in the North and in the South. The most common classes are open low-rise (LCZ 6) and sparsely built (LCZ 9). The north-western part of the city includes large low-rise (LCZ 8). The dominant land cover types around the city are bare soil and low plants. These areas temporarily change within a year because of their agricultural use thus these two LCZ categories were merged. Since multiple satellite images of different dates were used to classify the different LCZs, the merging of the two zones simplifies the classification.

MUKLIMO_3

In this study the microclimatic model MUKLIMO_3 was used (Sievers, U. 1995). It was developed by the German and Austrian weather services (DWD and ZAMG). The model is non-hydrostatic and the precipitation is not implemented. The horizontal resolution is 100 m, while the vertical one alters from 10 to 100 m. The vertical grid distance is lower so the resolution is larger towards the surface. Several parameters are necessary for the description of buildings, for instance building density, wall area for a given volume and mean building height (Früh, B. *et al.* 2011a). The initial conditions are ensured by a 1D profile from a reference station.

The interactions between the atmosphere and the vegetation are simulated by a 3-layer model and between the soil and the atmosphere by a 15-layer model. The land use categories distinguished by MUKLIMO_3 are buildings, trees, open country and water. The outputs of the model are the spatial patterns of air temperature, humidity, wind speed and direction for every hour in a 24-hour period (for details see Sievers, U. 2012).

Cuboid method

In order to calculate the mentioned climate indices the so-called cuboid method was used (Früh, B. *et al.* 2011a). This is a dynamical-statistical downscaling technique, which provides the spatial pattern of the climate indices for a 30-year period. The benefit of this method is the reduction of the computations using a tri-linear interpolation scheme. *Figure 2* shows the concept of the cuboid. The method assumes that the urban heat load can occur in a specific combination of meteorological parameters and it can be characterized by three of them: temperature (t), relative humidity (rh) and wind speed (ws). These parameters represent the dimensions of the cuboid, while the limit of favourable situations represents the corners of the cuboid. With the MUKLIMO_3 model we simulated these corners for two prevailing wind direction: Northeast and Northwest. In addition to these simulations, a 30 year daily data series is needed, which was measured near the study area or obtained from a climate model.

Meteorological data

As reference station the observatory of Hungarian Meteorological Service *(Figure 1)* was used. This station ensured the initial conditions for the modelling and the 30 year daily dataset for the reference period (1981–2010) in the cuboid method. Air temperature, humidity, wind speed and direction data were utilized.

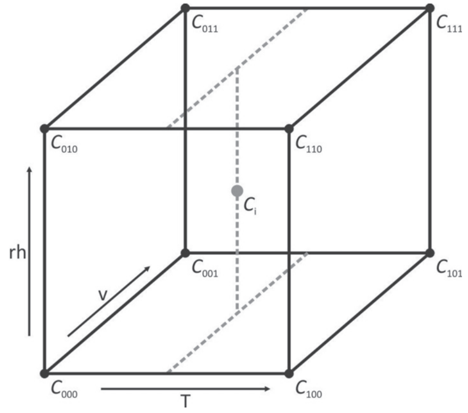


Fig. 2. The concept of the cuboid method (for details see Zuvela-Aloise, M. *et al.* 2014)

EURO-CORDEX simulations

We analyzed the 21st century through two periods: 2021–2050 and 2071–2100. For these periods we used temperature, humidity, wind speed and direction datasets from EURO-CORDEX model simulations (Jacob, D. *et al.* 2014). The resolution of the simulations is 0.11° (approximately 12 km) and they use the latest Representative Concentration Pathways (RCP) scenarios. These scenarios express the change in radiative forcing and are not directly based on socioeconomic factors. 15 simulations (5 global climate models and 3 regional climate models) were used where the necessary climate data for the cuboid method (temperature, relative humidity, wind speed and direction) was available. Among them there are one simulation for RCP 2.6 and seven simulations for RCP 4.5 and RCP 8.5. The simulations for the last two scenarios were averaged. In order to show the outcomes of more model simulations, we present the averaged results of scenarios RCP 4.5 and RCP 8.5.

Results

Warm nights

Thirty year averaged number of warm nights in period of 1981–2010 range from 1 day to 73 days in the entire model domain *(Figure 3)*. In the central part of the city, in a relatively smaller area, the number of days is over 60, but generally it exceeds 40 days in the whole city centre and it is over 20 days in other urban parts. In the downtown (where compact mid- and low-rise zones are located) most of the values are between 42 and 57 days (*Figure 3)*. In the surrounding areas (mostly open mid- and low-rise categories) the number of warm nights is between 12 and 40 days. In

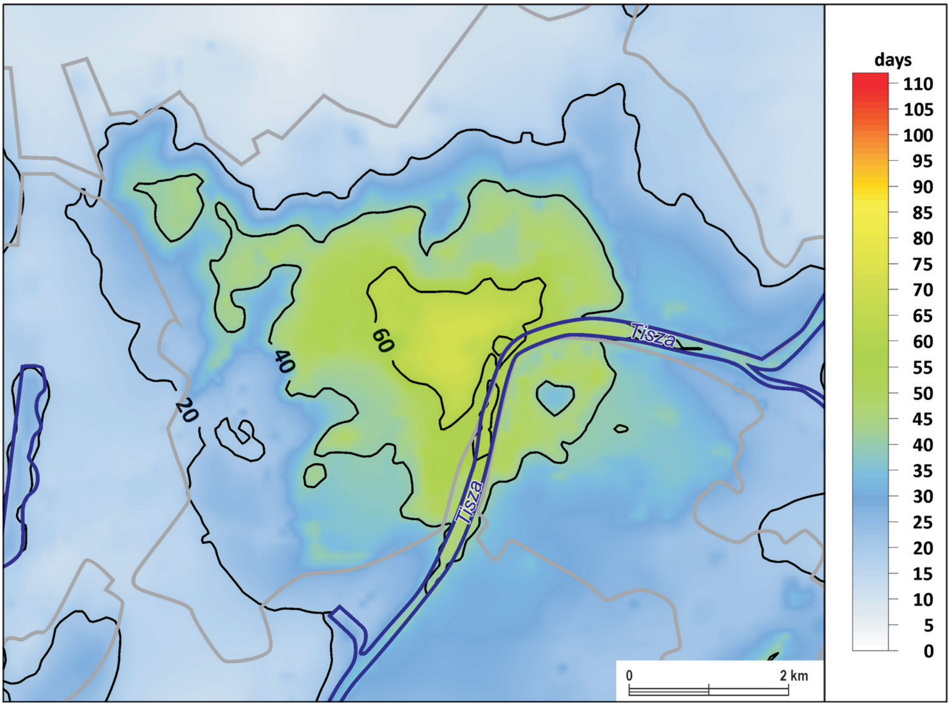


Fig. 3. Average number of warm nights ($T_{min} \geq 17$ °C) in period of 1981–2010. Grey lines = border of built-up areas; blue lines = border of water surfaces

western part of the city where the large low-rise class is typical, the values are about 13 to 23 days. In the perimeter of the city where the typical category is sparsely built, the values are between 12–21 days. In non-urban areas the value of warm nights is below 15 days except at larger water surfaces.

The 30-year mean number of warm nights based on RCP 4.5 and RCP 8.5 scenarios for period 2021–2050 is presented on *Figure 4*. In this period there is no significant difference between the two examined scenarios and the deviation from period 1981–2010 is minimal in both cases. Consequently, their features can be described together. In this period the values range from 1 to 80 days in the whole examined area. The most conspicuous change is the outspread of the area with values over 20 days. This tendency can be observed along the border of the city in northeast and southwest. Around the city centre all of the isolines spread towards the suburbs especially in case of the 40 days, but is notable in case of the 60 days also.

Considering the LCZs, in the areas of the compact zones in the inner city, the average number of warm nights is between 46 and 65 days. The mean values for the open zones which appear in more different parts of the city are about 14–39 days. In the sparsely built and large low-rise zones, which are more typical in the outskirts, the average number of warm nights is approximately between 14 and 28 days, but near to the city centre values over 40 days appear also. Most of the natural surfaces have less than 20 days in this period, but especially near the Western city border and in the water surfaces the number of warm nights is over 20 days.

For the period 2071–2100, significant changes are taking place, especially in case of RCP 8.5 compared to the reference period

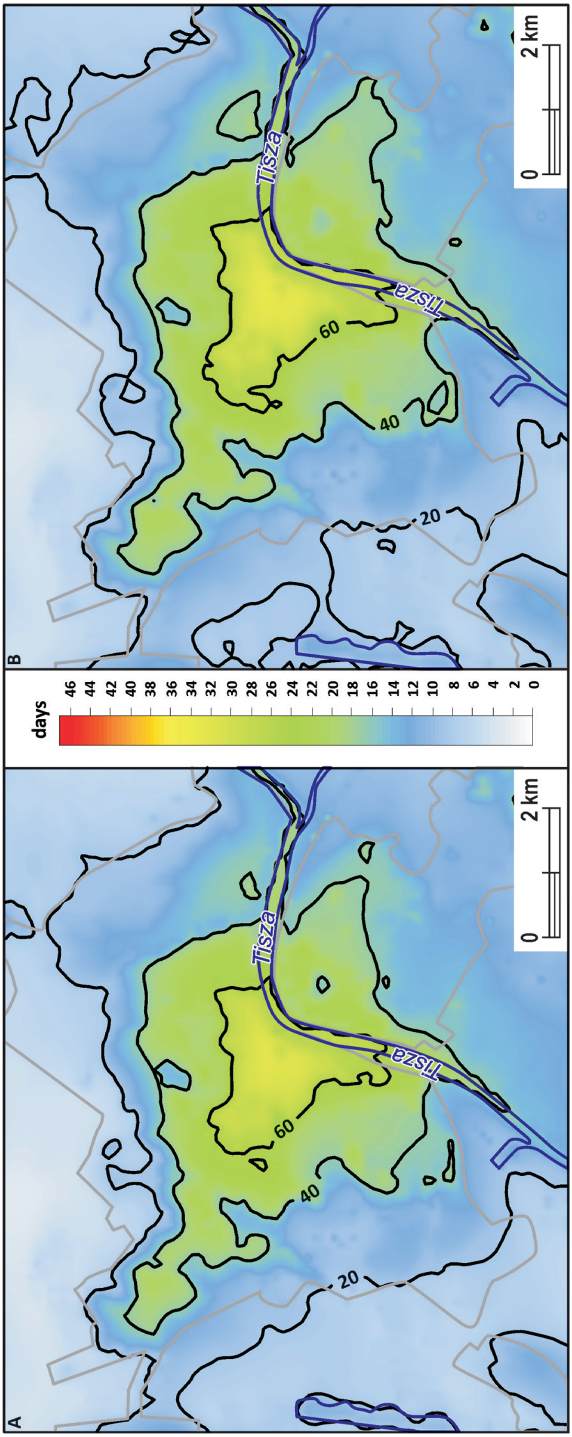


Fig. 4. Average number of warm nights ($T_{min} \geq 17$ °C) in period of 2021–2050 based on scenario RCP 4.5 (A) and RCP 8.5 (B). Grey lines = border of built-up areas; blue lines = border of water surfaces

(Figure 5, A). In the entire model domain, the minimum value for RCP 4.5 is 2 days and the maximum is 88 days, while in case of RCP 8.5 the values range from 12 to 111 days. In case of RCP 4.5, aside from the north-northeast region, the number of warm days is over 20 days in the examined area. It can be noted that the area of days over 40 around the city extends significantly. Moreover, spatial extent of the number of days over 60 stretches from the city centre towards the external areas.

In the inner-city values over 80 days become typical. In the compact zones the number of warm nights is between 60 and 80 days. In case of the open zones, there is larger difference between mid-rise and low-rise areas, while in the first case the values are approximately 50 to 77 days, in low-rise these numbers are 30 to 60 days. In the large low-rise and sparsely built zones the values are between 20 and 60 days can be found. In the natural and water surfaces, the number of warm nights is 20–30.

In case of RCP 8.5, the number of warm nights has a similar spatial distribution, but the values are higher by approximately 20 days *(Figure 5, B).* Almost in the entire study area the number of warm days is over 40 days, and values over 60 days appear in rural areas as well. Significant changes take place in the city centre which is surrounded by the isoline of 60 days. In the inner areas, values over 80 days are typical, while in the city centre the number of warm nights exceeds 100 days in a substantial area.

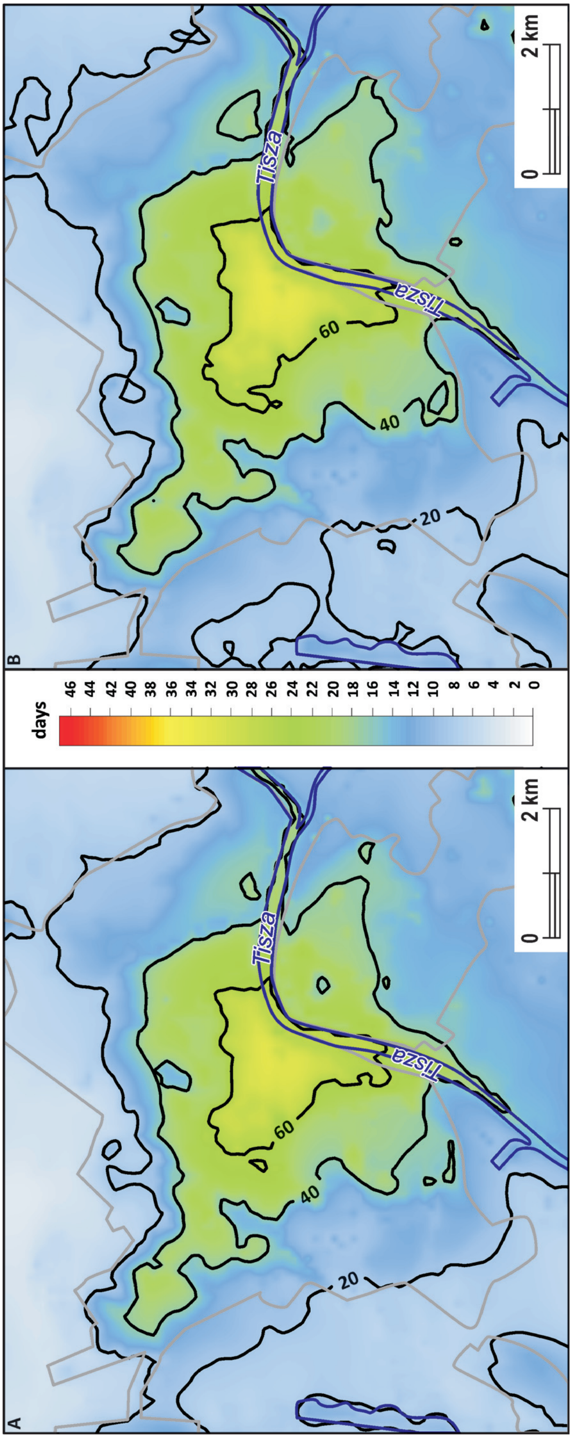


Fig. 5. Average number of warm nights ($T_{min} \geq 17$ °C) in period of 2071–2100 based on scenario RCP 4.5 (A) and RCP 8.5 (B). Grey lines = border of built-up areas; blue lines = border of water surfaces

Considering the local climate zones the typical values for the compact zones are between 80 and 110 days. In the open midrise zone the number of warm days is also high, approximately 75–95 days, while in open low-rise this is 52–80 days. In the outskirts (large low-rise and sparsely built) the values are between 50 and 90 days. The natural surfaces also have large values, of 43 to 58 days.

Evaluation of the average number of warm nights as well as the absolute and relative change from 1981–2010 compared to each examined future periods and scenarios in the typical LCZ areas helps to analyse how the LCZ classes are exposed to the climate change *(Table 1).* In period 2021–2050 the greatest relative change appears in sparsely built zone at both scenarios. It is followed by the open zones and the large low-rise zone. In case of RCP4.5 the changes in compact midrise and low-rise is marginal while in case of the natural surfaces there is no average change at all. The order is the opposite in case of RCP 8.5, where the change is the smallest in compact midrise and low-rise zones. In the natural surfaces this number is almost the same.

In period of 2071–2100 the greatest change also appears in sparsely built areas in case of both scenarios *(Table 1).* The natural surfaces follow this zone as the second most changed areas. This zone is followed by open midrise, low-rise and large low-rise, where open low-rise has the largest value. The smallest relative changes appear in compact midrise and low-rise.

Table 1. Number of warm nights and their absolute and relative change compared to the measured values in 1981–2010 in LCZ areas of Szeged at different time periods and RCPs

Time period	RCPs	Compact-midrise	Compact low-rise	Open midrise	Open low-rise	Large low-rise	Sparsely-built	Natural surfaces
1981–2010	Measured	71	67	41	37	42	12	18
2021–2050	RCP 4.5	75	72	47	42	47	15	18
		4	5	6	5	5	3	0
		6	7	15	14	12	25	0
	RCP 8.5	78	74	49	44	49	17	20
		7	7	8	7	7	5	2
		10	10	20	19	17	42	11
2071–2100	RCP 4.5	86	82	58	53	58	22	26
		15	15	17	16	16	10	8
		21	22	41	43	38	83	44
	RCP 8.5	110	107	85	81	85	49	51
		39	40	44	44	43	37	33
		55	60	107	119	102	308	183

Tropical nights

High numbers of tropical nights ($T_{min} \geq 20$ °C) are relatively uncommon in this climate and the model calculations also confirmed this in case of 1981–2010 *(Figure 6)*. The values range from 0 to 12 days. It can be noted that the values do not exceed 5 days except in the densely built areas. However, the number of tropical nights exceeds 10 days in the inner city core.

Considering the number of tropical nights through the different LCZs, there are no significant difference between the zones. Most of the values range from 4 to 11 days

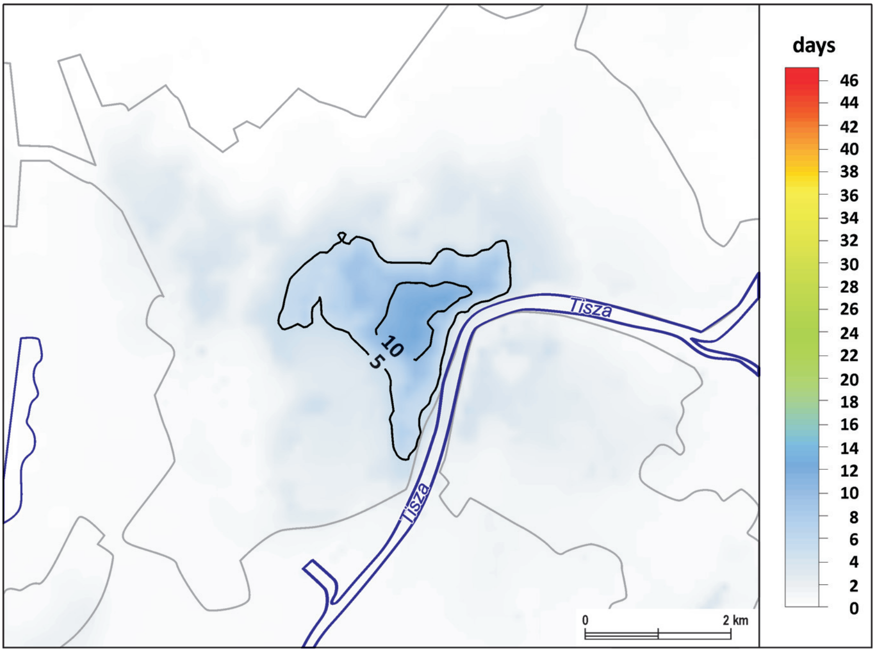


Fig. 6. Average number of tropical nights ($T_{min} \geq 20$ °C) in period of 1981–2010. Grey lines = border of built-up areas; blue lines = border of water surfaces

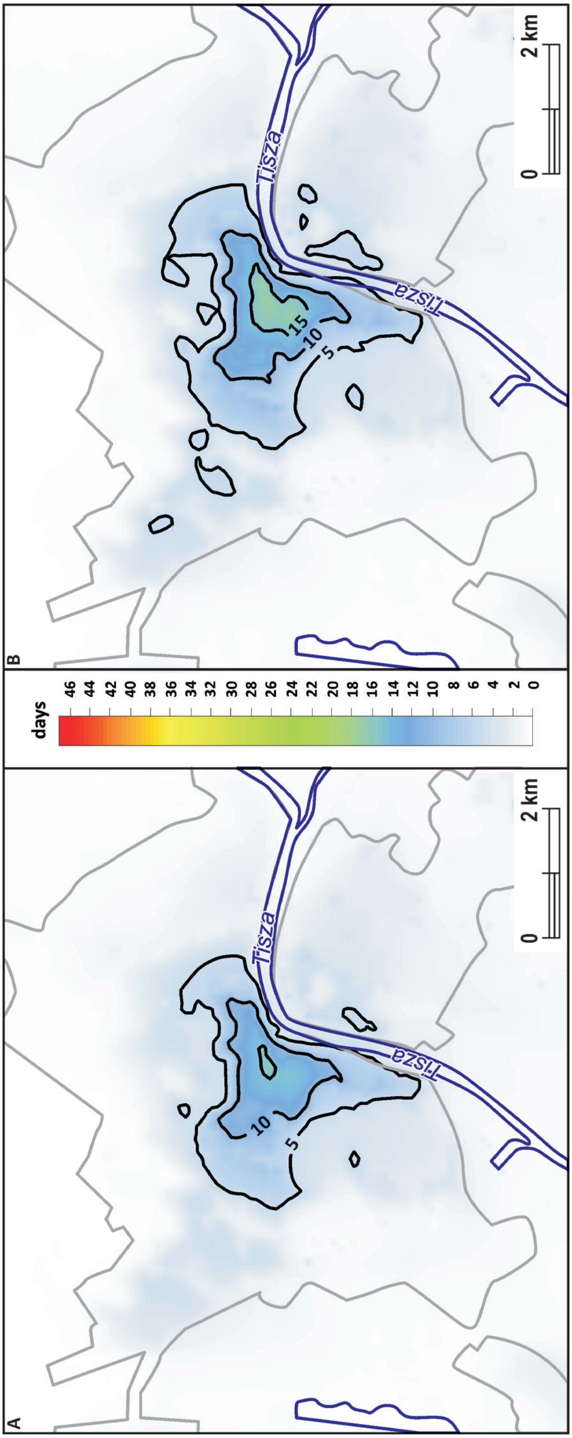


Fig. 7. Average number of tropical nights ($T_{min} \geq 20$ °C) in period of 2021–2050 based on scenario RCP 4.5 (A) and RCP 8.5 (B). Grey lines = border of built-up areas; blue lines = border of water surfaces

in compact midrise and from 6 to 11 days in compact low-rise. In the open midrise zone the number of tropical nights exceeds 5 days in the inner city. In case of large low-rise and sparsely built, most of the values range from 0 to 3 days, while in case of open midrise from 0 to 5 days. In the natural and water surfaces, the majority of the values is around 0.

The change from period of 1981–2010 is not significant in case of both scenarios and the difference between them is minimal *(Figure 7).* The minimum value is 0 day for each scenarios, the maximums are approximately 16–17 days. In both cases, the areas with over 5 days increase in the city centre and in addition they appear scattered in other regions. In case of RCP 8.5, the mentioned change is more spectacular and the number of the affected regions is larger. The isoline of 10 days spreads also, especially into north-western and north-eastern direction. The other important change is the appearance of values over 15 days in the city centre. It is minimal in case of RCP 4.5, but in case of RCP 8.5, the area with values over 15 days covers a significant part of the inner city.

Considering the LCZs slightly greater change can be observed in case of compact midrise and compact low-rise. Most of the values range from 5 to 14–16 days depending on the scenarios in compact midrise. For compact low-rise, the average number of tropical nights varies from 10 to 13–14 days. In case of open midrise

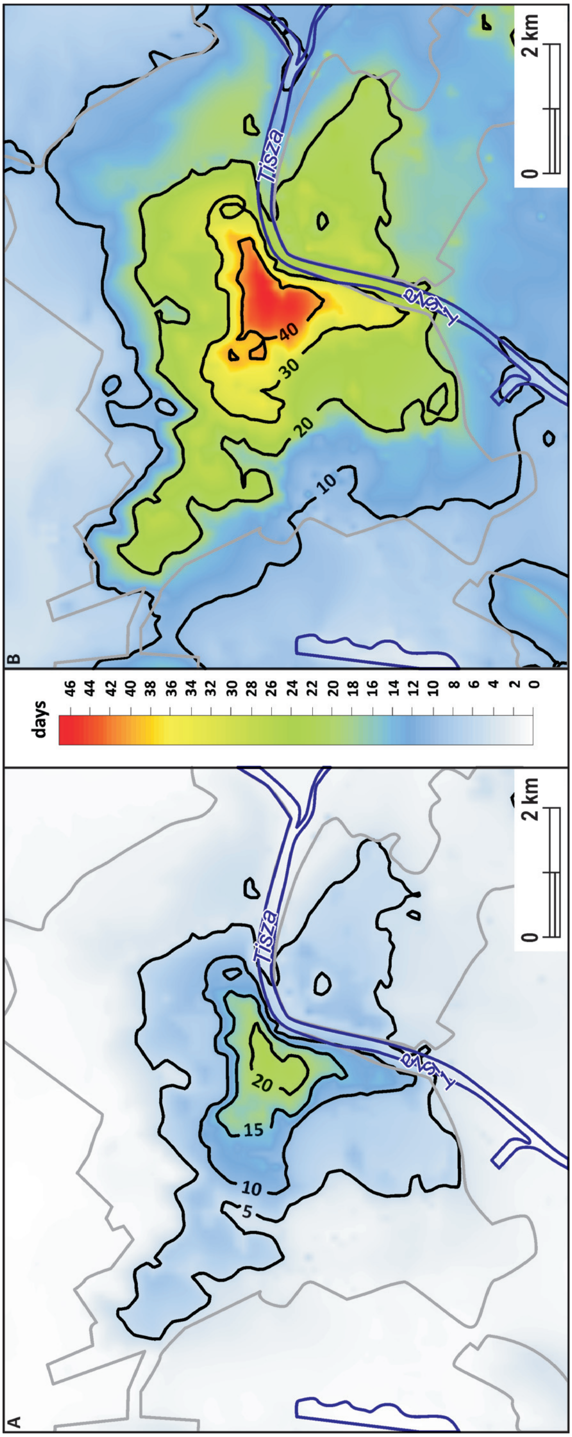


Fig. 8. Average number of tropical nights ($T_{min} \geq 20$ °C) in period of 2071–2100 based on scenario RCP 4.5 (A) and RCP 8.5 (B). Grey lines = border of built-up areas; blue lines = border of water surfaces

and low-rise, the change is minimal. The change is not noticeable in large low-rise and sparsely built, and neither in the natural and water covered surfaces.

At the end of the century (2071–2100) the difference between the two scenarios is remarkable *(Figure 8)*. The minimal value for RCP 4.5 is 0 day, the maximum is 23 days, while these numbers for RCP 8.5 are 1 day and 47 days. While in case of scenario RCP 4.5, the change from period 2021–2050 is minimal, in RCP 8.5, the changes are enormous and spectacular. Based on the first scenario *(Figure 8, A)* the area with values over 5 days continues to grow and stretches to the East side of the Tisza and north-western direction from the city centre. In the centre the areas with values more than 10 and 15 days also increase. Another change is that values over 20 days appear in the city.

Considering the LCZs in case of RCP 4.5, the change compared to the reference period is the largest in the compact zones. In these zones most of the values range from 16 to 21 days. In the other zones the change is less remarkable; generally, the increase is below 2 days. In the natural and water surfaces the average change is only 1 day from the reference period like in period 2021–2050.

The results of scenario RCP 8.5 give a very different picture *(Figure 8, B)*. The number of tropical nights is over 5 days. On the East side of the Tisza values over 10 days are typical and in a larger area the number of tropical nights is over 20 days.

The urban areas are outlined by the isoline of 15 days. In the densely built up areas the number of tropical nights is over 30 days and in the city centre it exceeds 40 days.

The average values for compact zones are between 35 and 45 days. In case of open midrise, most of the values are between 20 and 30 days. In open low-rise the values vary from 10 to 30 days. In case of large low-rise and sparsely built the typical number of tropical nights ranges from 10 to 30 days and from 10 to 25 days, respectively. In areas of natural surfaces the change is 7–8 days on average compared to the reference period.

Table 2 presents the average number of tropical nights in every LCZ type and their absolute and relative change compared to 1981–2010 in the examined periods based on the two applied scenarios. It should be noted that since the number of tropical nights in LCZ 9 is 0 day in the reference period thus the relative change in the future periods cannot be calculated. In period 2021–2050 the relative changes are the highest in open mid-rise. In case of RCP 4.5 the second large change appears in open low-rise. The values of compact low-rise and large low-rise are almost the same. Compact midrise follows these zones. In the natural surfaces, there is no change compared to period 1981–2010. In case of RCP 8.5 large low-rise is the second largest changed zone. This zone is followed by open low-rise and midrise. Similar to RCP 4.5 compact midrise is the least changed among the build-up zones.

The most noticeable changes also appear in open midrise in the period 2071–2100 in both scenarios. In case of RCP 4.5, it is followed by open low-rise again. The difference is similar in large low-rise. In compact midrise and low-rise, this value is slightly smaller. According to this scenario, the relative change in the natural surfaces is still zero percent. In case of RCP 8.5 the second largest change is in open low-rise. However, the relative change in the natural surfaces becomes also high and exceeds the value of large low-rise. The least changed zones are compact midrise and low-rise.

Conclusions

This study presented the changes in the number of warm and tropical nights during the 21st century compared to period of 1981–2010 in Szeged. We examined the spatial distribution of these indices and the number of days and their change through the different local climate zones. Furthermore, the difference between the relative changes of the zones was also investigated.

Our results show the substantial increasing tendency for both indices. The spatial

Table 2. Number of tropical nights and their absolute and relative change compared to the measured values in 1981–2010 in LCZ areas of Szeged at different time periods and RCPs

Time period	RCPs	Compact midrise	Compact low-rise	Open midrise	Open low-rise	Large low-rise	Sparsely built	Natural surfaces
1981–2010	Measured	12	10	2	2	3	0	1
2021–2050	RCP 4.5	14	13	4	3	4	0	1
		2	3	2	1	1	0	0
		17	30	100	50	33	–	0
	RCP 8.5	16	14	5	3	5	0	1
		4	4	3	1	2	0	0
		33	40	150	50	67	–	0
2071–2100	RCP 4.5	21	19	8	6	8	1	1
		9	9	6	4	5	1	0
		75	90	300	200	167	–	0
	RCP 8.5	45	42	25	21	26	8	9
		33	32	23	19	23		8
		275	320	1150	950	767	–	800

pattern shows that most of the days appear in the city centre stretched to the Northwest direction and values decrease towards to the natural surfaces. In period of 2021–2050, the change compare to the reference period and the difference between the two scenarios is not significant. In contrary, for the end of the century the increase is more significant and the two scenarios predict completely different spatial patterns.

The results also show that high values appear at compact LCZs in case of both indices. It is also noticeable that the increase of the number of days is higher in the less built LCZs, however the differences between LCZs do not change significantly. In case of warm nights, the largest relative change appears in sparsely built zone, followed by the natural surfaces and open zones while the smallest values are in the compact zones. For tropical nights the order is slightly different because the most changing zone is open midrise.

This study intended to highlight the interaction between urban climate effects and global climate change. The results clearly prove that global or regional scale climate predictions without urban climate interactions do not have enough information for urban planners or local authorities. In addition, the results can be used as a good example for the demonstration of the expected changes of the climate of 21th century. Using these results the presentation of climate change in urban scale to wider audience is easier. The increasing number of tropical nights can be used to express the change of unfavourable and stressful conditions until the end of the century. The number of tropical nights will be almost the same in rural areas at the end of the century as today in the city centre. Furthermore, in the most urbanized areas one month of this extreme heat stress may become a natural part of every summer. This is a crucial problem because if the minimum temperature exceeds 20 °C then a significant increase of the relative number of deaths can be observed.

Hopefully, these results help to draw attention of urban planners and local governments or local decision makers for this problem and based on the model results for different LCZs it may be helpful to find the optimal built-up characteristics for urban areas in order to mitigate the effect of climate change.

***Acknowledgements*:** The study was supported by the International Visegrad Fund, Standard Grant No. 21410222, by the Hungarian Scientific Research Fund (OTKA K-111768) and the second author was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. We acknowledge the CORDEX project for producing and making available their model output. Special thanks to Boudewijn van Leeuwen for the language revision of the manuscript.

REFERENCES

Bechtel, B., Alexander, P.J., Böhner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L. and Stewart, I. 2015. Mapping local climate zones for a worldwide database of the form and function of cities. *ISPRS International Journal of Geo-Information* 4. (1): 199–219.

Bokwa, A., Dobrovolny, P., Gál, T., Geletič, J., Gulyás, A., Hajto, M.J., Hollósi, B., Kielar, R., Lehnert, M., Skarbit, N., Stastny, P., Svec, M., Unger, J., Vysoudil, M., Walawender, J.P. and Zuvela-Aloise, M. 2015. Modelling the impact of climate change on heat load increase in Central European cities. In *International Conference on Urban Climate (ICUC 9.* Extended abstracts, 5 p.

Früh, B., Becker, P., Deutschländer, T., Hessel, J.D., Kossmann, M., Mieskes, I., Namyslo, J., Roos, M., Sievers, U., Steigerwald, T., Turau, H. and Wienert, U. 2011a. Estimation of climate change impacts on the urban heat load using an urban climate model and regional climate projections. *Journal of Applied Meteorology and Climatology* 50. (1): 167–184.

Früh, B., Kossmann, M. and Roos, M. 2011b. *Frankfurt am Main im Klimawandel – Eine Untersuchung zur stadtischen Warmebelastung. Berichte des Deutschen Wetterdienstes 237.* Offenbach am Main, Selbstverlag des Deutschen Wetterdienstes, 68 p.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O.B., Bouwer, L., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B. and Yiou, P. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. *Regional Environmental Change* 14. 563–578.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F. 2006. World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15. (3): 259–263.

Lehnert, M., Geletič, J., Husák, J. and Vysoudil, M. 2015. Urban field classification by "local climate zones" in a medium-sized Central European city: the case of Olomouc (Czech Republic). *Theoretical and Applied Climatology* 122. (3): 531–541.

Lelovics, E., Unger, J., Gál, T. and Gál, C.V. 2014. Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modeling. *Climate Research* 61. (1): 51–62.

Sievers, U. 1995. Verallgemeinerung der Strom-funktionsmethode auf drei Dimensionen. *Meteorologische Zeitschrift* 4. 3–15.

Sievers, U. 2012. *Das kleinskalige Strömungsmodell MUKLIMO_3 Teil 1: Theoretische Grundlagen, PC-Basisversion und Validierung*. Offenbach am Main, Berichte des Deutscher Wetterdienst, 136 p.

Stewart, I.D. and Oke, T.R. 2012. Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society* 93. 1879–1900.

Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A. Xia, Y., Bex, V. and Midgley, P.M. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate*. Cambridge and New York, Cambridge University Press, 1535 p.

Unger, J., Sümeghy, Z., Gulyás, Á., Bottyán Z. and Mucsi, L. 2001. Land-use and meteorological aspects of the urban heat island. *Meteorological Applications* 8. 189–194.

Zuvela-Aloise, M., Koch, R., Neureiter, A., Böhm, R. and Buchholz, S. 2014. Reconstructing urban climate of Vienna based on historical maps dating to the early instrumental period. *Urban Climate* 10. (3): 490–508.

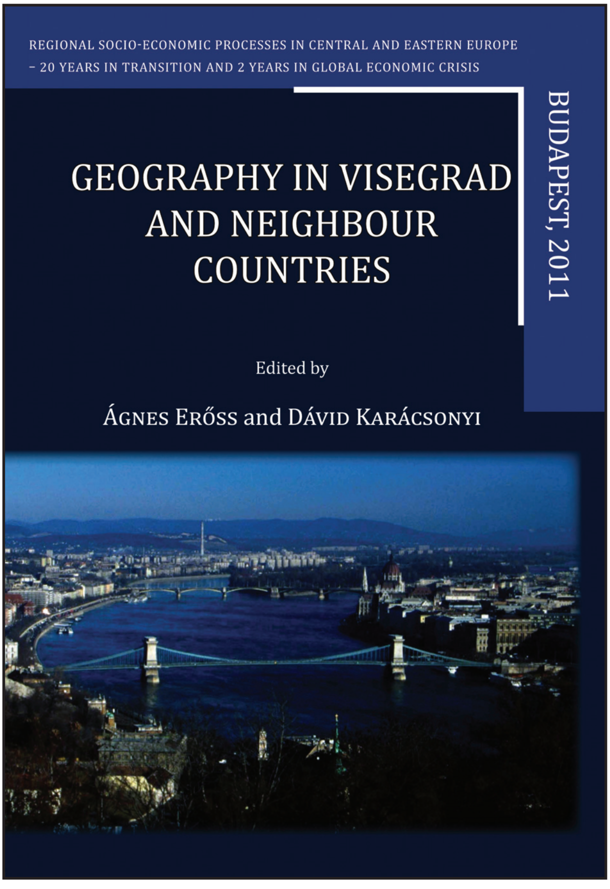
Geography in Visegrad and Neighbour Countries

Regional Socio-Economic Processes in Central and Eastern Europe – 20 Years in Transition and 2 Years in Global Economic Crisis

Edited by
Ágnes Erőss and Dávid Karácsonyi

Geographical Research Institute Hungarian Academy of Sciences
Budapest, 2011. 169 p.

During the last twenty years the erstwhile Soviet bloc countries in Central and Eastern Europe (CEE) have taken distinct routes in post-socialist development, wherein the national trends and internal regional processes proved to be in deep contrast. Responses to the challenges of the global economic crisis also varied, repeatedly brought to the surface long existing regional issues, structural problems and ethnic conflicts. Human geographers are divided in the assessment of the shifts that occurred during the past twenty years and the exchange of experience is vital for finding adequate answers to the new challenges. In order to provide a forum for discussion the Geographical Research Institute Hungarian Academy of Sciences with the generous support of the International Visegrad Fund Small Grant Programme organized a conference in order to induce the revival of contact between the institutes of geography of Visegrad Countries and their Western and Eastern neighbours. Present volume is a selection of presentations aiming to provide a deeper insight in socio-economic processes and their



Price: EUR 10.00
Order: Geographical Institute RCAES MTA Library, H-1112 Budapest, Budaörsi út 45.
E-mail: magyar.arpad@csfk.mta.hu