FINAL REPORT – OTKA-111768 (2015–2018)

1. BASICS

1.1. Measurement data

Within the framework of an EU project (http://urban-path.hu) we set up – in Central and Eastern Europe unique and also globally rare – monitoring network with 22 elements (air temperature – T, air humidity - RH) in Szeged (Gál, Unger 2016, Unger et al. 2017a). This network automatically records the measured data every 10 minutes and transmits to a central server in our department. To them the data series of the HMS (OMSz) stations at the road to Baja (rural) and at the university (urban) are added (air temperature, relative humidity, solar radiation, wind, cloud cover). The selection of the network station sites was based on the Local Climate Zone (LCZ) map of Szeged and its surroundings: two stations represent the rural area, while the other 22 stations the different built-up areas of the city. From 2014 onwards the network continues to provide data.

1.2. Numerical methods, software and additional datasets

The WRF (Weather Research and Forecasting) is a freely-accessed and open-source numerical weather prediction model. In the frame of the project we adopted the WRF model in our servers. During the work multiple model setup was tested and numerous numerical experiments was carried out. For the simulation we applied the GFS forecasts as a forcing.

Additionally, during the project we applied several other software and methods (e.g. statistical software /SPSS, MATLAB/, processing programs /GrADS/, simulation models /RayMan, UMEP/, GIS software /ArcGIS, Erdas, QGIS, Google Earth, SAGA GIS/ and developed algorithms in Fortran language).

For the proper application of WRF model a detailed urban surface dataset is necessary, thus we evaluated several surface parameters in the study area complimenting the previously available datasets. For this work we applied own developed algorithms and GIS methods (Skarbit and Gál, 2015).

2. COMMITMENTS – DELIVERABLES

2.1. Development of algorithms for quantifying of human comfort conditions in the study area

For the calculation of the measure of human comfort (Physiologically Equivalent Temperature – PET) the multilayer perceptron (MLP) network structure was developed. The input data (T, RH, wind speed, global radiation, time) were derived from the field measurements carried out in different urban microenvironments in Szeged between 2009 and 2013. The target output data for the learning was a PET dataset calculated from the same input by the widely used RayMan software. The MLP model always has one hidden layer and MLP has several parameters that need to be set (training time, learning rate, hidden layers, and neurons in the layers). The training time was 1500 epochs, the learning rate started from 0.3 and it was reduced in each step. The number of hidden layers and the nodes in each layer were generated automatically by the WEKA data mining software (Unger et al. 2015a). As a result, the last 48-hour variation of PET data at the typical urban and rural stations in Szeged is presented online for the public (http://adatok.geo.u-szeged.hu/human-bioklima.php).

2.2. Development of the appropriate method for the spatial interpolation of the measurement data of the monitoring network

After the transmission of the station data into the main server, the automatic data procession system creates the final two (site and spatial) databases in order to make it possible to present these data as charts and maps. The received data are stored in one text file per day on the server and also stored in a MySQL database. Every 10 minutes a Java software calculates the PET value describing the human comfort conditions for each station using the T and RH values measured there, as well as global radiation and wind speed data measured at the HMS stations. The results of this calculation are also stored in the MySQL database.

For the automatic interpolation of the spatial patterns of the measured and calculated data for a 500 m resolution grid of the study, a Java software was developed. In order to avoid the incorrect interpolation in the edge of the study area, the two rural stations were considered as background stations, thus, at the bordering (non-urban) grid points we used the data of the nearest rural station, and all of these points were added to the original measurement points for the interpolation. The coordinates of the grid points and stations are in the Unified Hungarian Projection, but at the end of the interpolation they were converted to WGS84 coordinates, because it is more appropriate for the further processing (drawing maps with GrADS, comparing the measurements with weather prediction models). At the first hand, we applied a weighting constant (currently it is 1) in the interpolation. After further investigations, we altered this constant using the statistical connection between the surface parameters (e.g., built-up ratio, SVF, green area, water surface) and the measured T, RH, or PET values in order to increase the precision of the interpolation. The final patterns are stored in another, spatial database, which is a NetCDF file (Unger et al. 2015a).

Several field measurements were organized at nocturnal hours (from sunset to sunrise) of days with clear and calm weather (negligible cloud cover, wind speed). For the measurements we applied 2 reserve (T+RH) sensors of the monitoring system. The measurement sites were located at several areas near to river Tisza, one sensor placed on the top of the rampart and the other at the river level. According to the obtained data the river has only minor effect on the air temperature in the city.

2.3. Analysis of the spatial and dynamic climatology of the urban heat island (UHI) and the human comfort conditions within the city

We analyzed the spatial pattern of UHI and its dynamical background based on the network dataset of Szeged. Our results showed that the UHI is stronger in the compactly built districts and there are great differences between the districts. The greatest values appeared in summer, while the difference was small in winter. The UHI started to develop at sunset and existed through approximately 9–10 hours and differences were about 2 °C larger in case of ideal days, when the weather conditions (wind, cloud cover) promoted the micro- and local climatic effects of the surface features. The cooling rates showed that the first few hours after sunset were determinative for the developing of UHI. After sunrise the city warmed slower than the rural areas, therefore, the urban cool island also occurred. In addition, the effect of UHI on the annual mean temperature is also significant (Gál et al. 2016; Gál, Unger 2016, Skarbit et al. 2018). We also made the performance verification of the T+RH sensors (Lelovics et al. 2016).

Considering the moisture content in the urban canopy layer first we compared the intra-urban relative and absolute humidity patterns showing an example based on a long (three-year) dataset from the network of Szeged. The comparison clearly demonstrated the usefulness of the utilization of absolute measure opposite to the temperature dependent relative one. This supports the earlier statements found in the literature albeit these statements were based on only case studies or short datasets (Unger et al. 2018b). The general features of the annual and diurnal variations of mean urban-rural absolute humidity (e) differences found in cities with mid-latitude climates were also detectable: the nocturnal absolute humidity difference is positive throughout the year while the diurnal course changes its sign, as well as the largest daytime deficit and nocturnal excess occur in April and in September, respectively. The diurnal course of the summer urban *e* pattern in normalized 4-hour time steps did not show a regular shape, the patterns were mosaic-like: in all time steps the driest and wettest areas were mainly in the north-western and south-eastern parts, respectively (Unger et al. 2018c).

2.4. Validation of different thermal reactions of the Local Climate Zones (LCZ) types occurring in Central European environment

First, we compared and integrated two LCZ classification methods based remote sensing (Bechtel – B) and GIS (Lelovics-Gál – LG), respectively. We conducted the initial classification using the B method, since it needs only few and globally available input data. Then the aggregation of the LG method was implemented in a JAVA tool, in order to create LCZs of sufficient size. As the results showed the highly data-intensive LG method and globally applicable B method produceed slightly different LCZ maps. The combination of these methods may be useful and helps to improve the B method. Since it does not require any additional input data, the main advantage of the process is remained and it can be applied globally in any urban area without remote sensing and GIS expert knowledge (Gál et al. 2015, Bechtel et al. 2019).

For a preliminary investigation we concentrated only on the intra-urban T pattern characteristics expressed by the thermal reactions of the different LCZ classes during the most heat loading season (summer). The evaluation of the daily temperature indices ('summer days', 'tropical nights') revealed that the highest frequencies of 'tropical nights' occurred in the most densely built LCZ classes (2, 3, and 5). Based on these results, the control of building densities or the spatial confinement of dense LCZs could be viable adaptation strategies. Further, in order to assess the thermal behavior of different LCZs under 'ideal' conditions, two periods with anticyclonic conditions were selected, when the distinction between the daily temperature cycles of different LCZ classes was quite pronounced. The average daily cycle of each LCZ highlighted the differences between day- and nighttime processes. The diurnal variation of conventional heat island intensity confirmed the general knowledge that it remains positive with highest values at night, while negative values occur predominantly during the day (Unger et al. 2015b, Lelovics et al. 2016).

Further, we analyzed the long-term thermal characteristics of LCZ classes in average and 'ideal' weather conditions using the so-called weather factor. We provided detailed site metadata for each of the monitoring stations used in the analysis. We found that the densely built-up LCZ classes have higher annual and monthly mean and minimum air temperatures than structurally open and more vegetated classes, with nocturnal differences of >4°C observed under calm, clear skies. We measured temperature indices for different LCZ classes within Szeged: 'frost days' were more frequent in areas of the city with natural cover and open structure, while 'tropical nights' were more frequent in areas of impervious cover and compact structure. Owing to such localized differences in T, energy demand for building heating decreases toward the compact, built-up core of Szeged in the winter months, while in summer months the core experiences greater nocturnal cooling demand due to heat island effects. This difference suggests that local climatology exists within Szeged, and that this has implications for thermal comfort, urban energy use, and urban agriculture. By reporting these results with standardized indices, definitions, and climatic classes, we encouraged meaningful comparisons with other cities, and easy delivery of climate information to urban planners and local governments (Skarbit et al. 2016, 2017, 2018, Unger et al. 2017a, Gál et al. 2018).

Additionally, as a case study, we investigated the surface temperature (Ts) characteristics of the different LCZs in Szeged. We applied high resolution Ts data acquired by a low-cost small-format digital imaging system, measured in early night hours. The obtained Ts values were different in the different LCZs: the open low-rise type (LCZ 6) had the lowest early night-time Ts within the most densely populated LCZ types. Thus, to decrease the thermal load in urban areas then the preference of this built type LCZ type can be a solution for the urban residents (Skarbit et al. 2015).

According to the study on intra-urban absolute moisture (e) content the largest *e* means occurred in summer while the smallest ones in winter and in the transitional seasons the values were between them with a bit higher *e* means in autumn. There was no clear sequence in the annual and seasonal mean values of LCZs that would follow the differences in the compactness or building height of the zones and even the built-up versus land cover distinction. The intra-zone differences can be larger than the inter-zones since the effect of microscale environment was essential. The decisive factors were the permeability of the surface and the vegetation cover. The higher impervious surface indicated lower, while natural surfaces, mostly the proximity of trees indicated higher values (Unger et al. 2018c).

We gave a comprehensive picture on the diurnal and seasonal general outdoor human thermal sensation levels in different urban quarters based on long-term data series from urban and rural areas of Szeged and on the utilization of the PET index with categories calibrated to the local population.. This intra-urban comparison was supplemented with a case study dealing with an extreme heat wave period which is more and more frequent in the last decades in the study area. The results showed that the seasonal and annual average magnitudes of the thermal load exerted by LCZs in the afternoon and evening follow their LCZ numbers. This LCZ sequence of thermal load means that in the daytime, the most pleasant zones are the less built ones, but in the evening, the situation will turn; namely, the inner urban parts are more pleasant to spend the leisure time outdoors. It is perfectly in line with the LCZ concept originally concentrating only on T-differences between the zones. During the selected heat wave period there were no distinguishable thermal sensations in the different zones during the daylight hours. Contrary to this, the thermal sensations at night could clearly be separated by LCZs. Our results justified the subdivision of urban areas into LCZs and gave significant support to the application possibilities of the LCZ concept as a broader term covering different thermal phenomena (Skarbit et al. 2017b, Unger et al. 2017b, 2018a).

2.5. Development of a short-term Now Casting forecasting method for urban areas

We adopted the WRF model (version: 3.7.1.) and carried out numerous (more than 500) numerical experiments in order to define the optimal model setup, input parameters, input surface classification and numerical solutions. For the analysis we applied the 0.25° resolution GFS dataset as a forcing. Our main task was to evaluate the different urban surface parametrization methods of the modelling software. Also a new (more accurate and detailed) surface database was created for the model domain using multiple Landsat satellite images. To find the optimal model setup the summer of 2015 was simulated. We compared the different model setups and validated the results using the urban climate monitoring system (Gyöngyösi et al. 2016, Molnár et al. 2016).

We finalized the application of the LCZ scheme in WRF system. The physical characteristics of the LCZ classes were estimated using sample areas in Szeged. The final LCZ based modelling strategy was tested in several-week long periods, in order to analyze the model performance. For the verification the monitoring network data were used (Molnár et al. 2017a. 2017b, 2019a 2019b).

We also tested the model performance during unfavorable weather conditions when the occurrence of UHI is unwilling. These experiments revealed the limitations of the methodology in fog situations, however the possible solutions were also identified (Molnár et al. 2018).

The work with the weather forecast in urban areas using LCZ system was a part of a wider theoretical work, in the frame of this initiative we compared the final model performance with another numerical simulation model (Gál et al. 2018). This analysis revealed that the concept of urban canyon in modelling methods was a crucial limitation. There were several urban areas where the urban canyons cannot be defined adequately, and in these areas the model outputs were less proper. This comparison was only a first step of this analysis, however it opened a new topic for urban climate modelling initiatives of our research group.

Besides the scientific utilization we developed an operational urban heat island prediction tool using the WRF, in order to draw the attention of the wider public to the effect of the urban climate. This two-day long operational forecast runs in each day using the 0 UTC GFS outputs. The forecasted temperature outputs for an urban and rural pixel and the magnitude of UHI are visualized in dynamic charts in the homepage of our department (http://www.clima.u-szeged.hu/monitoring/varosi-hosziget).

Molnár G, Gyöngyösi AZ, Gál T, 2019a: Modeling of urban heat island with adjusted static database. Időjárás (in press)

Molnár G, Gyöngyösi AZ, Gál T, 2019b: Integration of an LCZ-based classification into WRF to assess the intra-urban temperature pattern under a heatwave period in Szeged, Hungary. Theor Appl Climatol (in press)