MULTI-APPROACH ANALYSIS OF URBAN HEAT ISLAND EFFECT IN A CENTRAL/EASTERN EUROPEAN AGGLOMERATION

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1. INTRODUCTION

The urban heat island (UHI) effect is probably the most often analyzed environmental phenomenon of large cities. We aim to use different approaches to evaluate the UHI effect of the agglomeration around the Hungarian Capital, Budapest (Probáld, 2014). The city is divided by the river Danube into the hilly, greener Buda side on the west, and the flat, more densely built-up Pest side on the east. The more specific target area within the city is the district IX (called Ferencváros, Fig. 1), where several block rehabilitation programs have been completed in the recent decades, which resulted in functional and structural changes of special subsections of the district.

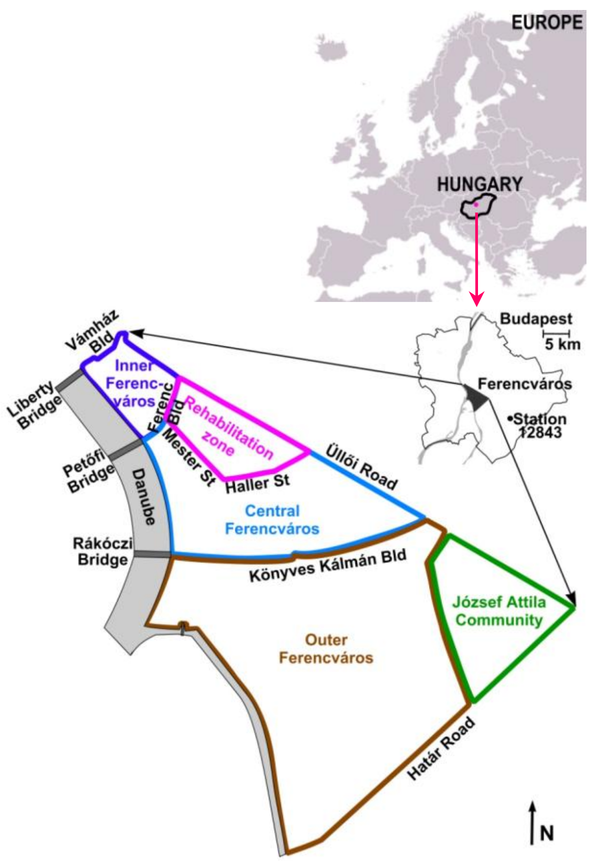

Fig. 1: Geographical location of the target city: Budapest, Hungary located in Eastern/Central Europe.

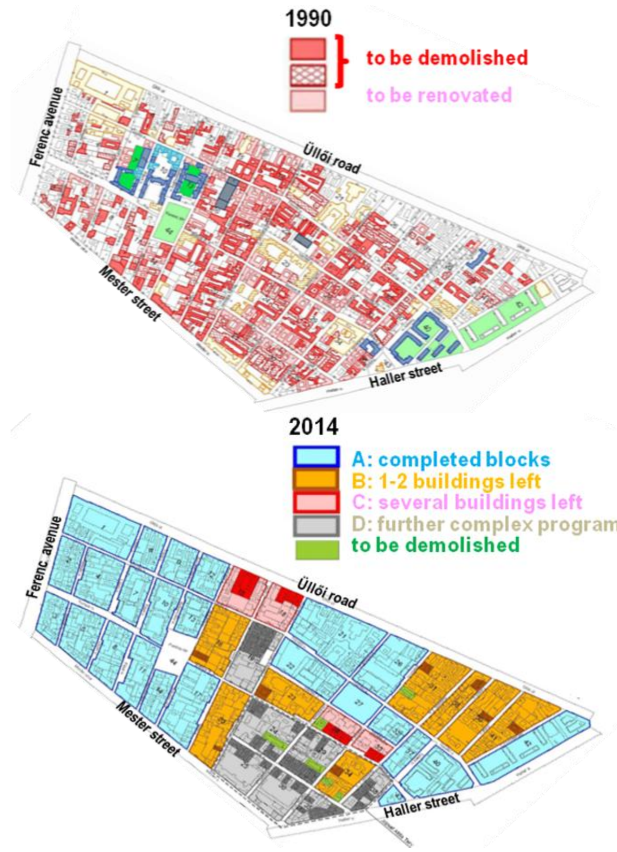

Fig. 2: Block rehabilitation program: accomplished changes in the rehabilitation zone between 1990 and 2014.

Ferencváros is located near the river Danube in the southern central part of Budapest, which is very heterogeneous and consists of 3- and 4-storey old buildings, block houses with either 4 or 8 levels, brown industrial areas, and large areas occupied by the railways system. Partly due to the functional and structural changes of the special subsections of the district substantial local climatic changes occurred in the past few decades. Concentrated efforts of the local government completed several block rehabilitation programs starting from the 1980s. Since 1993 in the most densely built inner part of the district entire blocks were renovated and modified in order to create more livable environment for the citizens. Altogether 220 houses (with ~1300 apartments) were demolished with new buildings were built in their places, 49 houses

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(with ~1050 apartments) were renovated by today (Fig. 2). About 7% of planned demolishing and 65% of planned renovation (LGF, 2010) are still ahead of the Local Government. Within the framework of the block rehabilitation programs the inner parts of the blocks were demolished, thus, inside the blocks more common green areas could be created (Fig. 3). Moreover, several parks have been enlarged, and small green areas have been created along the streets (LGF, 2010). The overall increase both in terms of number and spatial extension of green areas is illustrated in Fig. 4.

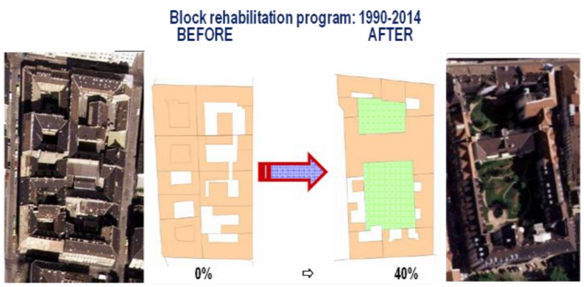

Fig. 3: Structural change of buildings in the framework of block rehabilitation program, 1990–2014.

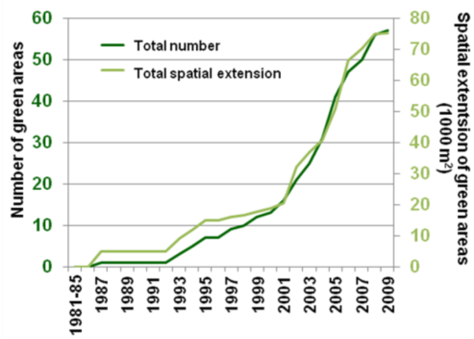

Fig. 4: Increase of the green areas in Ferencváros, the district IX of Budapest (LGF, 2010)

This study analyzes measurements (both in-situ and satellite) as well, as mesoscale modeling of the target area.

2. ANALYSIS OF IN-SITU MEASUREMENTS

We completed several measuring campaigns with 24-hour continuous in-situ measurements of temperature and humidity in Inner and Central Ferencváros including the rehabilitation zone of the district IX of Budapest during different weather conditions and different seasons. The measuring program started in the early spring of 2015. The measurements were scheduled once a week from 2 p.m. on Thursdays to 2 p.m. on Fridays. In addition, summer campaigns (in July 2016, 2017, 2018) covered at least 72 hours continuously. The on-going measuring program involves BSc students specialized in Earth sciences and MSc students specialized in meteorology. Altogether 77 days with more than 850 hours of measurements are collected by now.

Fig. 5: The complex measuring instrument Testo-623 with data logger.

Air temperature and relative humidity were recorded with Testo-623 instruments (Fig. 5) along a pre-defined path consisting of 23 measuring points (Fig. 6), which covers the studied area.

201: Ferenc bld. / Tompa st.
202: Bakáts sq. / Tompa st.
203: Bakáts sq. / Ráday st.
204: Ráday st. 42
205: Ráday st. / Biblia st.
206: Ráday/Erkel st
207: Kálvin sq.
208: Lónyay st. / Gönczy st.
209: Csarnok sq.
210: Building Bálna
211: Nehru Park
212: Boráros sq.

101: Ferenc bld. / Tompa st.
102: Tompa st. / Liliom st.
103: Liliom st. / Tűzoltó st.
104: Tűzoltó st. / Bokréta st.
105: Ferenc sq.
105n: Passage
106: Balázs st. / Thaly st.
107: Univ. Building
108: Kerekerdő Park
109: Márton st./ Gát st.
110: Mester st. /Viola st.
111: Mester st. / Tinódi st.
112: Boráros sq.

Fig. 6: Measuring points along the predefined path.

The measuring sites were selected at different representative points of the district, such as green parks, narrow streets, paved squares and roads (Pongrácz et al., 2016). The whole measuring path is divided into two parts, where the measurements are recorded simultaneously (from 101 to 112, and 201 to 212 with the identical starting and ending sites, i.e., 101 is identical to 201, and 112 is 212) lasting about 1-1.5 hours. Then, the measurements are recorded along the same two paths but in reverse order (i.e., starting from 112/212, and ending at 101/201). In order to temporally adjust the measurements, two records from the consequent (and reversed) partial paths are averaged over each site resulting in an average value being representative for a virtual time. More precisely, since the moving speeds between sites and the distances between sites are not perfectly identical, this virtual time is given as a 10-20 minute time period. For calculating the UHI intensity, temperature measurements were compared to the hourly recorded data of the Budapest synoptic station (ID number: 12843) located in the southeastern suburb district of the city (shown in Fig. 1). Similarly, difference between relative humidity measurements were also calculated and analyzed.

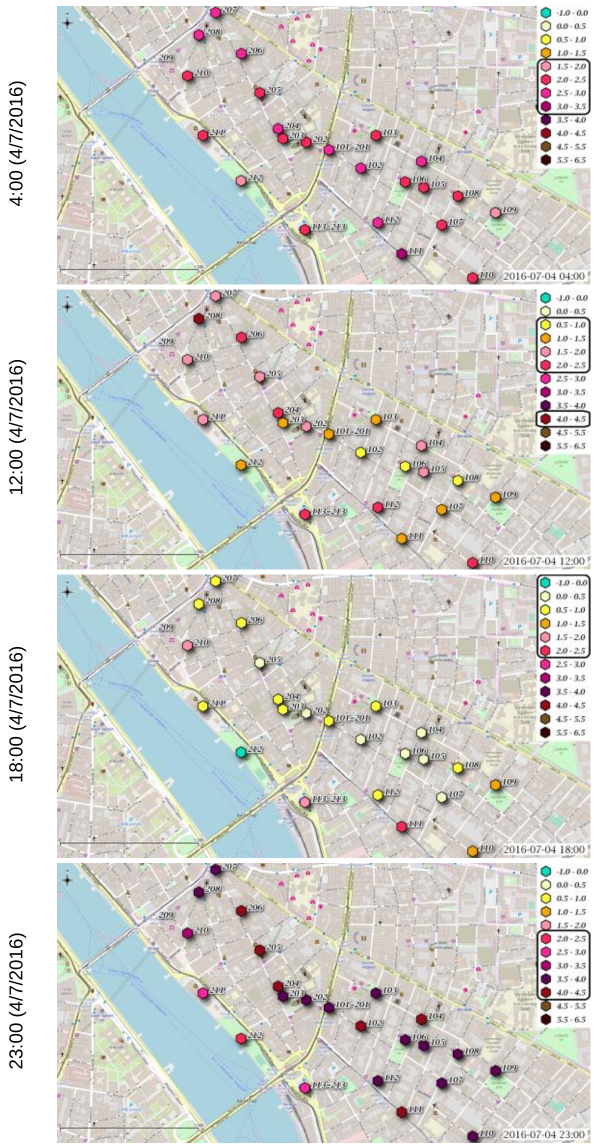

Fig. 7: The daily cycle of the spatial patterns of UHI intensity, 4 July 2016.

First, some results from the summer campaign in 2016 (July 4–6) are shown in Figs. 7–8. The synoptic situation during the days of the measuring campaign was ideal to detect the UHI effect, namely, anticyclonic circulation over the Carpathian basin with >1020 hPa sea level pressure and clear sky conditions.

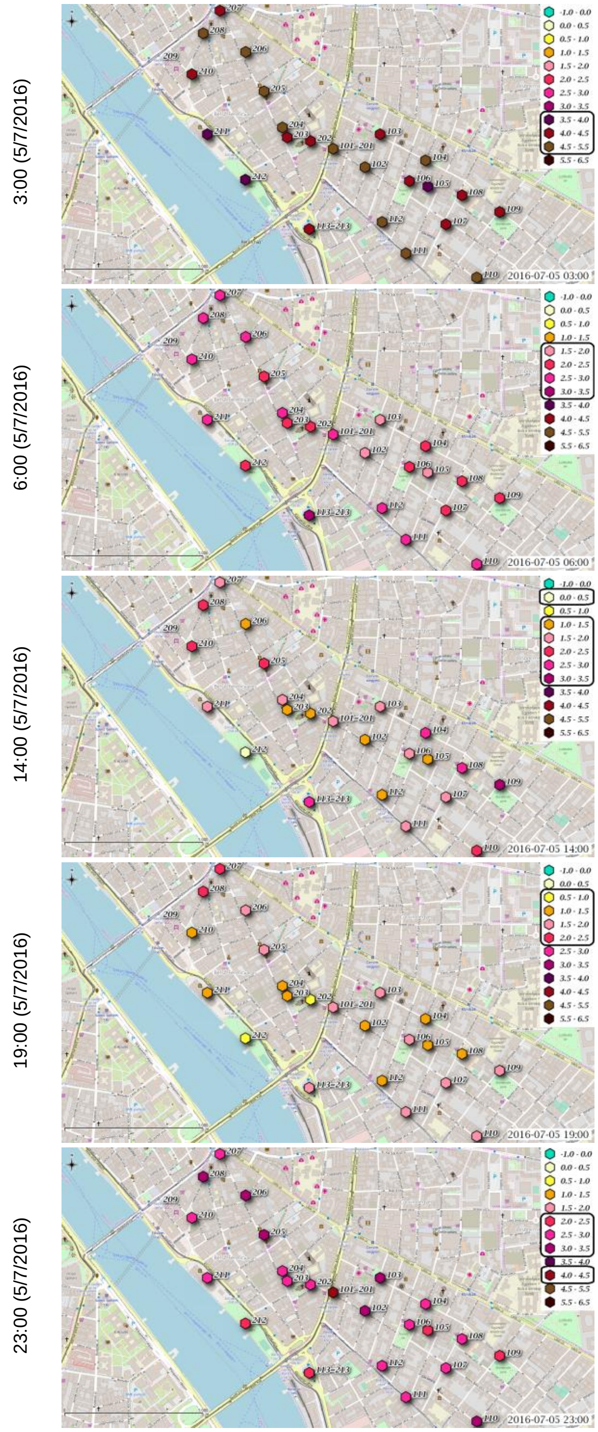

Fig. 8: The daily cycle of the spatial patterns of UHI intensity, 5 July 2016.

In addition to the spatial structure, a more detailed analysis of the daily cycle of UHI intensity is carried out. One example from the summer campaign in 2016 is shown in Fig. 9 for the measuring point 105n, which is located in a passage surrounded by buildings with a height of about 20 m, the vegetation cover is ~60% (Fig. 10).

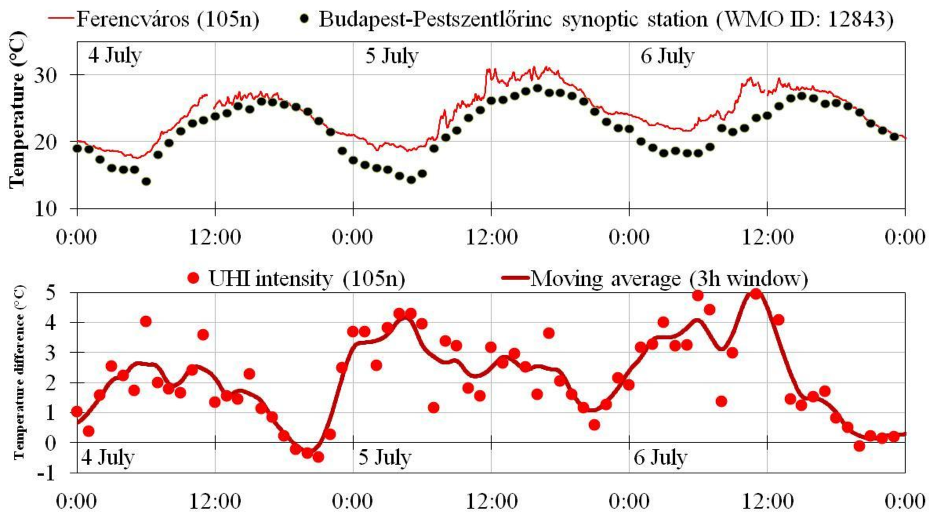

Fig. 9: The daily cycle of temperature measurements (at measuring site 105n compared to the synoptic station of Budapest, WMO ID: 12843), 4–6 July 2016.

Fig. 10: Measuring site 105n.

The graph of Fig. 9 clearly indicates that the measuring site in the inner city is warmer than the southeastern suburbs of Budapest. The greatest UHI intensity, which is defined as the difference between the temperatures of measuring site 105n and the suburban-located synoptic station of Budapest, was detected during night time, in some days closer to dawn.

On the basis of the measurements in different seasons the relationships between the UHI intensity values and various weather conditions are evaluated. The strongest relationships were found between the maximum UHI intensity and the cloud cover (Fig. 11), namely, intense UHI occurs in clear sky conditions, whereas the UHI effect becomes quite small when cloudy conditions occur.

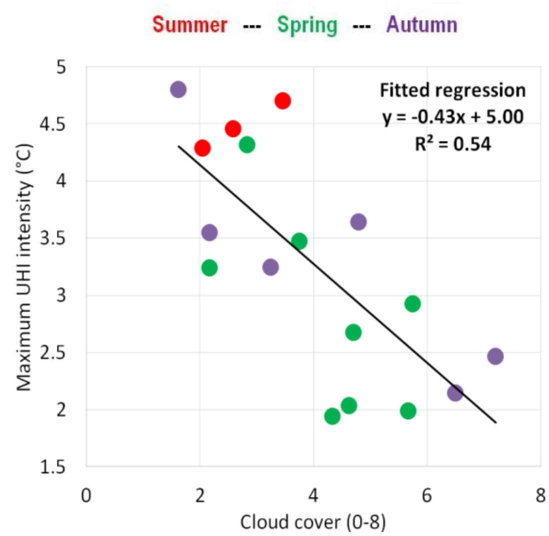

Fig. 11: Relationship between the maximum UHI intensity and cloud cover (2016-2018).

Although these measurements can be used to evaluate the temporal evolution of the UHI effect, they do not cover fully the agglomeration area. In order to provide a full spatial coverage of Budapest and its vicinity, satellite measurements serve as the basis of UHI analysis.

3. ANALYSIS OF SATELLITE MEASUREMENTS

For the purpose of analyzing the entire spatial coverage of the Budapest agglomeration area, surface temperature is used, which is derived (Wan and Snyder, 1999) from the radiation data of 7 infrared channels (channel 20: 3660-3840 nm, channel 22: 3929-3989 nm, channel 23: 4020-4080 nm, channel 29: 8400-8700 nm, channel 31: 10780-11280 nm, channel 32: 11770-12270 nm, and channel 33: 13185-13485 nm) measured by the sensor MODIS (Moderate Resolution Imaging Spectroradiometer) onboard satellites Terra (NASA, 1999) and Aqua (NASA, 2002).

MODIS is a cross-track scanning multi-spectral radiometer with 36 electromagnetic spectral bands from visible to thermal infrared. Horizontal resolution of the infrared measurements is 1 km. In the framework of EOS program numerous climatic and environmental parameters are determined using the raw radiation data. All the parameters are archived in universal format using 1200×1200 pixel tiles, they are available as validated, quality-controlled, geo-referenced, high-level datasets.

On the basis of error- and cloud-free parts of available surface temperature fields, SUHI (surface urban heat island) intensity values were calculated for 2001-2018 for each pixel within the 65×65 pixel representation of the Budapest agglomeration using the rural mean surface temperature LST (Bartholy et al., 2016).

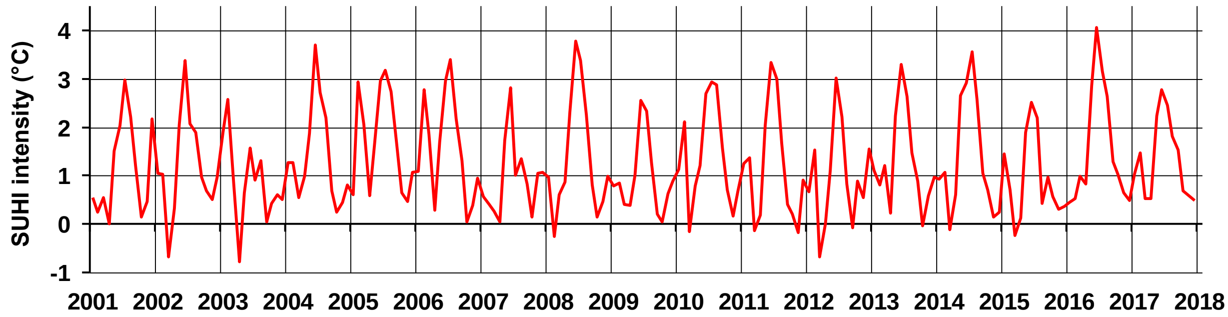

Fig. 12: The monthly mean SUHI intensity time series of Budapest on the basis of surface temperature determined from day-time Terra/MODIS measurements (2001-2018).

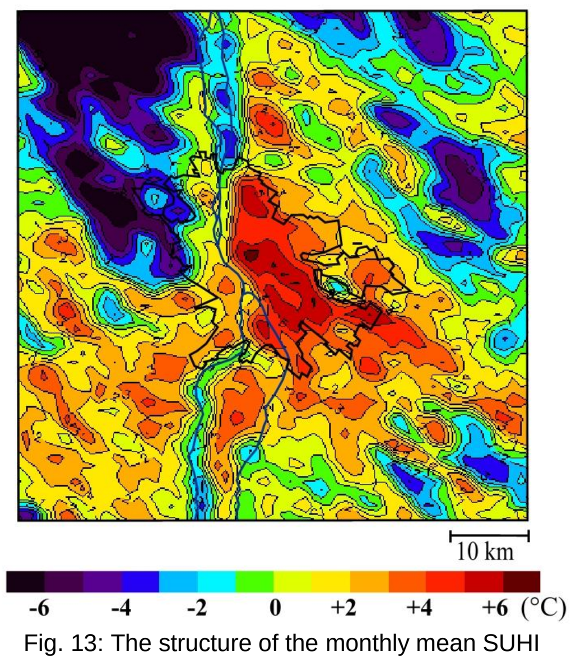

Fig. 13: The structure of the monthly mean SUHI intensity of Budapest on the basis of surface temperature determined from day-time Terra/MODIS measurements (June 2018).

The UHI results certainly differ when air temperature or surface temperature is taken into account. Fig. 12 shows the SUHI intensity time series of Budapest with maximum in summer (showing the structure in Fig. 13) and minimum in spring and late autumn. The more detailed analysis of the SUHI of Budapest is published in Pongrácz et al. (2006, 2010). The analysis of the connection of SUHI in Budapest to its Local Climate Zones (Stewart and Oke, 2012) can be found in Pongrácz et al. (2018).

4. MODELLING APPROACH

In addition to the measurements, mesoscale model simulations also have a great potential in analyzing the urban environment, especially, in terms of specific events (Göndöcs et al., 2018). We used the Weather Research and Forecasting (WRF) mesoscale model (Skamarock et al., 2008) coupled to multilayer urban canopy parameterization in our study to investigate the climatic conditions in their compexity for Budapest and its surroundings. For the winter and summer simulations the initial meteorological fields were derived from the publicly available GFS (Global Forecast System) outputs for the past, and a regional climate model (RegCM) for the future (Pieczka et al., 2018). To validate the simulation results, the calculated skin temperature over Budapest was compared (Göndöcs et al., 2017) to the surface temperature fields of the remotely sensed measurements of sensor MODIS. Moreover, the simulated air temperature fields were also evaluated, and special locations were selected to analyze the temporal evolution of UHI effect in details. RegCM-driven WRF simulations were analyzed to provide information for different users (including decision makers) on the future UHI effects of the Budapest agglomeration under different RCP scenarios (van Vuuren et al., 2011).

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REFERENCES

Bartholy, J., Pongrácz, R., Dezső, Zs., Dian, Cs., Fricke, C., 2016: Recent changes on the urban local climate using satellite data and in-situ measurements. In: *96th Annual Meeting of the American Meteorological Society*. New Orleans, LA. Paper 873, 8p. Available online at https://ams.confex.com/ams/96Annual/webprogram/Manuscript/Paper285360/Extended-paper-BJ-PR-DZs-DCS-FC_2016_AMS.pdf

Göndöcs, J., Breuer, H., Pongrácz, R., Bartholy, J., 2017: Urban heat island mesoscale modelling study for the Budapest agglomeration area using the WRF model. *Urban Climate*, 21, 66–86.

Göndöcs, J., Breuer, H., Pongrácz, R., Bartholy, J., 2018: Projected changes in heat wave characteristics in the Carpathian Basin comparing different definitions. *International Journal of Global Warming*, 16, 119–135.

LGF, Local Government of Ferencváros, 2010: Rehabilitation of Budapest Ferencváros. Budapest, 80p.

NASA, 1999: Science writers' guide to Terra. NASA EOS Project Science Office, Greenbelt, MD. 28p.

NASA, 2002: Science writers' guide to Aqua. NASA EOS Project Science Office, Greenbelt, MD. 32p.

Pieczka, I., Pongrácz, R., Bartholy, J., Szabóné André, K., 2018: Future temperature projections for Hungary based on RegCM4.3 simulations using new representative concentration pathways scenarios. *International Journal of Global Warming*, 15, 277–292.

Pongrácz, R., Bartholy, J., Dezső, Zs., 2006: Remotely sensed thermal information applied to urban climate analysis. *Advances in Space Research*, 37, 2191-2196.

Pongrácz, R., Bartholy, J., Dezső, Zs., 2010: Application of remotely sensed thermal information to urban climatology of Central European cities. *Physics and Chemistry of Earth*, 35, 95–99.

Pongrácz, R., Bartholy, J., Dezső, Zs., Dian, Cs., 2016: Analysis of the air temperature and relative humidity measurements in the Budapest Ferencváros district. *Hungarian Geographical Bulletin*, 65, 93-103.

Pongrácz, R., Bartholy, J., Dian Cs., Dezső, Zs., 2018: Intra-annual characteristics of the relationship between the surface temperature based urban heat island intensity and the local climatic zones. *98th Annual Meeting of the American Meteorological Society*. Austin, TX. Paper 569, 6p. Available online at https://ams.confex.com/ams/98Annual/webprogram/Manuscript/Paper336512/PR-BJ-DCs-DZs-AMS2018.pdf

Probáld, F., 2014: The urban climate of Budapest: past, present and future. *Hungarian Geographical Bulletin*, 63, 69–79.

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X.-Y., Wang, W., Powers, J.G., 2008: A Description of the Advanced Research WRF Version 3. NCAR/TN–475+STR, June 2008. – NCAR Technical Note.

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

van Vuuren, D.P., Edmonds, J.A., Kainuma, M., Riahi, K., Thomson, A.M., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S., 2011: The representative concentration pathways: an overview. *Climatic Change*, 109, 5–31.

Wan, Z., Snyder, W., 1999: MODIS land-surface temperature algorithm theoretical basis document. Inst. for Computational Earth Systems Science, Univ. of California, Santa Barbara. 77p.