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Analysing the climatic effects of local block rehabilitation programs in Budapest-Ferencvaros

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1. Introduction

One of the main environmental impacts of cities is the urban heat island (UHI) effect. UHI can be characterized by its intensity, which means the difference between urban and rural temperature. To determine the UHI intensity, several variables can be used, e.g., regular meteorological air temperature measurements at 2 m level (e.g., Oke, 1973), ground-based air temperature measurements using a moving vehicle (e.g., Unger et al., 2000), surface temperature data calculated from radiation measurements of satellites (e.g., Price, 1979; Pongracz et al., 2006), or remotely sensed surface temperature measurements placed on board of an aircraft (e.g., Ben-Dor and Saaroni, 1997). When surface temperature is used to describe the urban climate conditions, surface UHI (SUHI) effect can be evaluated. Within the framework of the urban climate research at the Department of Meteorology, Eotvos Lorand University, Budapest (Dezso et al., 2005, Pongracz et al., 2006, 2010), SUHI effects of several Hungarian and Central European cities have been analyzed using remotely sensed surface temperature. In this current paper, the focus is on a smaller subregion of the Budapest agglomeration area, namely, one of the 23 districts of the Hungarian capital.

Ferencvaros, the 9th district of Budapest is located along the river Danube, which divides the entire city and the downtown region into two parts. Budapest/Ferencvaros is a very heterogeneous part of the city consisting 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 special subsections of the district substantial local climatic changes occurred in the past few decades. From the local government concentrated efforts were made to complete several block rehabilitation programs already starting from 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. Within the framework of these programs inner parts of the blocks were demolished, thus, inside the blocks more common green areas could be created. Moreover, several parks have been enlarged, and small green areas have been created along the streets (Local Government of Ferencvaros, 2010). The overall increase both in terms of number and spatial extension of green areas is illustrated in Fig. 1.

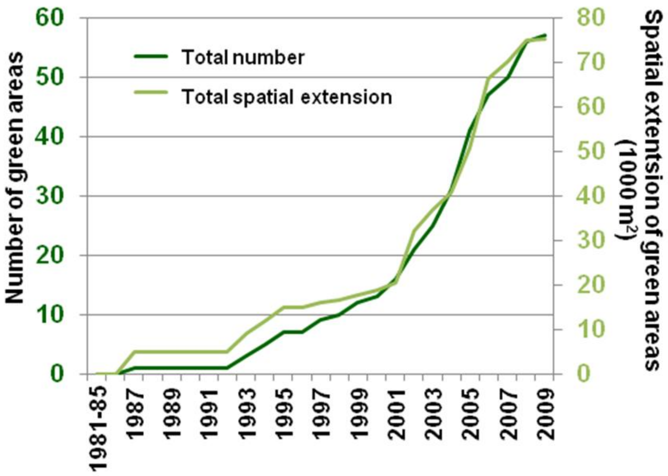


Fig. 1 Increase of the green areas in Budapest-Ferencvaros.

Here, the climatic effects are evaluated on the basis of satellite measurements, namely, surface temperature fields derived from radiation data of seven and five different infrared channels measured by sensor MODIS (onboard satellites Terra and Aqua), and sensor ASTER (onboard satellite Terra), respectively. From the surface temperature data rural mean values around Budapest are used to calculate pixelwise SUHI (surface urban heat island) intensity. Our main goal is to analyze whether the generally positive changes of the built environment can also be recognized in the urban heat island effect of this area.

2. Data

Part of the American National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS), satellites Terra and Aqua were launched in December 1999, and May 2002, respectively. They are on 705 km height polar orbits around the Earth with an inclination of 98°. Both satellites are solar-synchronous, Terra crosses the Equator on a descending orbit at 10.30 a.m., and Aqua crosses it on an ascending orbit at 1.30 p.m. Thus, for the Budapest agglomeration area, Terra can provide two images per day (at around 09-10 UTC and 20-21 UTC), as well, as Aqua (at around 02-03 UTC and 12-13 UTC). Five and six instruments are working on satellite Terra, and Aqua, respectively. These instruments measure radiation of various spectral bands and use different spatial resolution (NASA, 1999; 2002). Measurements of sensor MODIS (Moderate Resolution Imaging Spectroradiometer) and sensor ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) are used in this paper.

Sensor MODIS can be found on both satellites Terra and Aqua, and it 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 our research, MODIS Land Surface Temperature (LST) is used, which is determined on the basis of the measurements in the following infrared channels: 3,660-3,840 nm (channel 20), 3,929-3,989 nm (channel 22), 4,020-4,080 nm (channel 23), 8,400-8,700 nm (channel 29), 10,780-11,280 nm (channel 31), 11,770-12,270 nm (channel 32), and 13,185-13,485 nm (channel 33) as described by Wan and Snyder (1999). On the basis of error- and cloud-free parts of available LST fields, SUHI (surface urban heat island) intensity values are calculated for 2001-2013 for each pixel within the 65×65 pixel representation of the Budapest agglomeration using the rural mean LST value (Bartholy et al., 2012).

Sensor ASTER measures radiation in 14 different electromagnetic spectral bands, out of which 5 infrared channels (i.e., 8,125-8,475 nm, 8,475-8,825 nm, 8,925-9,275 nm, 10,250-10,950 nm, and 10,950-11,650 nm) are used to calculate surface temperature (NASA, 2001). ASTER can be found only onboard satellite Terra, and unlike sensor MODIS it is not turned on throughout the entire orbiting time, only for 8 minutes/orbit. Thus, the number of available information for a specific region is extremely limited. Nevertheless, the horizontal resolution of the measurements in thermal infrared channels is 90 m, which is far more suitable for detailed spatial analysis than MODIS data.

3. Results and discussion

Due to the data availability the temporal analysis is mainly based on MODIS data, whereas the spatial analysis uses ASTER data.

3.1 Analysis of MODIS data

For the temporal analysis two pixels are selected from the Budapest-Ferencvaros district (Fig. 2). Pixel I is located in the densely built-up region of the area where many block houses participated in the rehabilitation program, whereas pixel II represent a 4-storey buildings' community with large trees and many green areas.

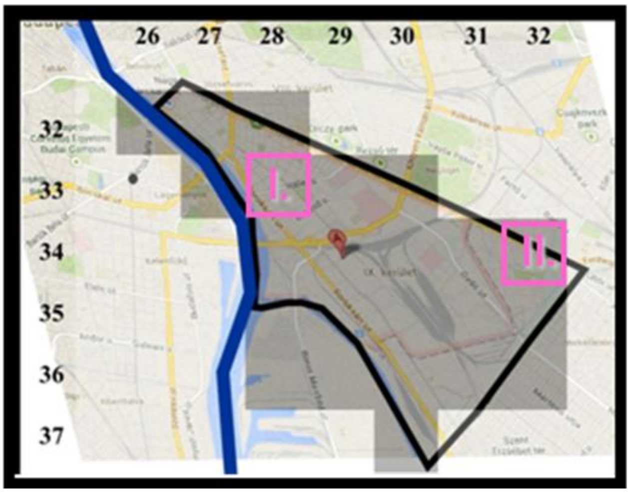


Fig. 2 Pixel representation of Budapest-Ferencvaros on the MODIS grid.
Pixels I (28;33) and II (32;34) are used for trend analysis shown in Fig. 3.

Monthly mean SUHI intensity values and average surface temperature in June are shown in Fig. 3 for pixels I and II. For this analysis, a summer month is selected with the afternoon measurements, when the SUHI intensity of the city is the largest (Bartholy et al., 2012). The fitted linear trends are positive in both pixels considering either SUHI intensity or surface temperature values. However, due to the large variability the trend coefficients are not significant at 0.05 level. The comparison of the two selected pixels suggest that the average surface temperature (and thus the mean intensity as well) is larger overall by about 1-2 °C in pixel II than in pixel I, which highlight the necessity of further increase of the green areas in the more densely built-up sections of the city. Moreover, finer spatial resolution may result in more details about the exact differences within the district.

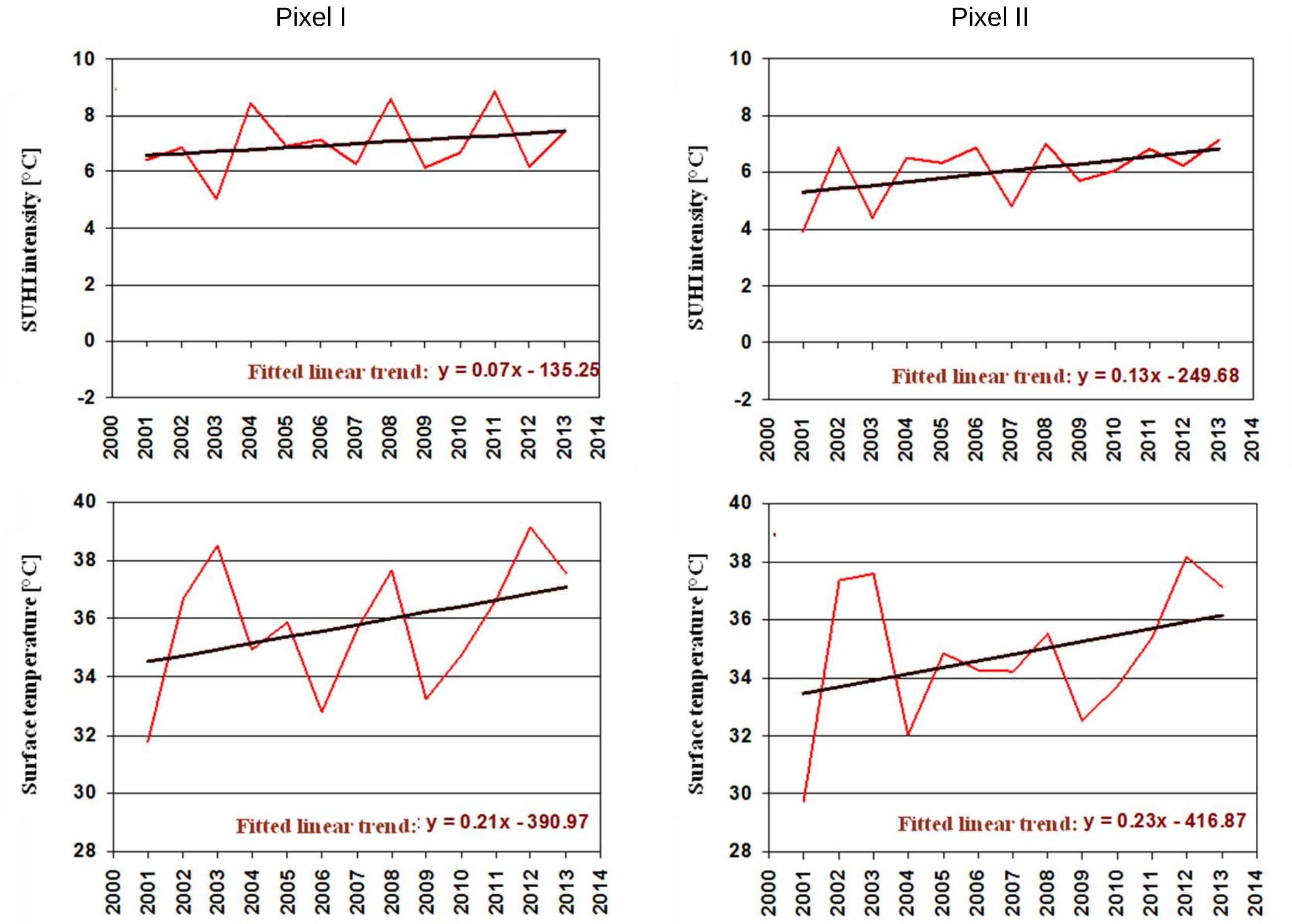


Fig. 3 Trend analysis for pixels I (28;33) and II (32;34), MODIS measurements in afternoon, June, 2001-2013

3.2 Analysis of ASTER data

1 km spatial resolution is too coarse for detailed analysis on house block scale. For this purpose, 90 m horizontal resolution ASTER data is more suitable than MODIS data. Available ASTER measurements covering the Budapest agglomeration area, more specifically, the Ferencvaros district form three different images (Fig. 4). Pixelwise SUHI intensity values are compared for a summer, a spring, and a winter day (6 July 2001, 4 May 2002, and 2 February 2003, respectively). The reference rural mean surface temperature value is calculated from the MODIS measurements for the particular days since ASTER images do not include the entire agglomeration area together with rural surroundings, thus, rural mean surface temperature cannot be determined on the basis of ASTER data only. The rural mean surface temperature value is very different in February (below 0 °C) from those in either July or May – when they were above 30 °C. Nevertheless, the calculated anomaly values enable us to identify hot and cold spots of the district.

Detailed descriptions of five major cold spots are shown in Fig. 5. These identified cold spots are basically all green areas with large trees, extended parks. The pixels of the spots are clearly colder than the adjacent pixels around them. However, their surface temperatures are still larger than the rural mean. Due to the large incoming solar radiation, the summer SUHI intensity values are the largest. Moreover, in winter – when the incoming solar radiation is much smaller – the SUHI intensity values themselves, as well, as the spatial variance of the SUHI intensity field are much smaller than in the rest of the year.

A similar list of the main hot spots is collected in Fig. 6. In these pixels, the SUHI intensity values in July are clearly above 10 °C. In early May, SUHI intemsity values of the hot spots are around 10 °C, except the supermarket area within the 4-storey buildings community. This area is especially vegetated with large, mature trees around, that is why the positive vegetation effect is partially eliminating the SUHI effect in spring-time when the shadows of the trees are the most effective. Finally, in winter-time the SUHI intensity values of the hot spots are smaller compared to the other two months, however, the differences of the surface temperature values between the selected hot spots and the rural mean are still around 7 °C, thus, the actual surface temperatures of these hot spots are above 0 °C despite of the freezing rural environment.

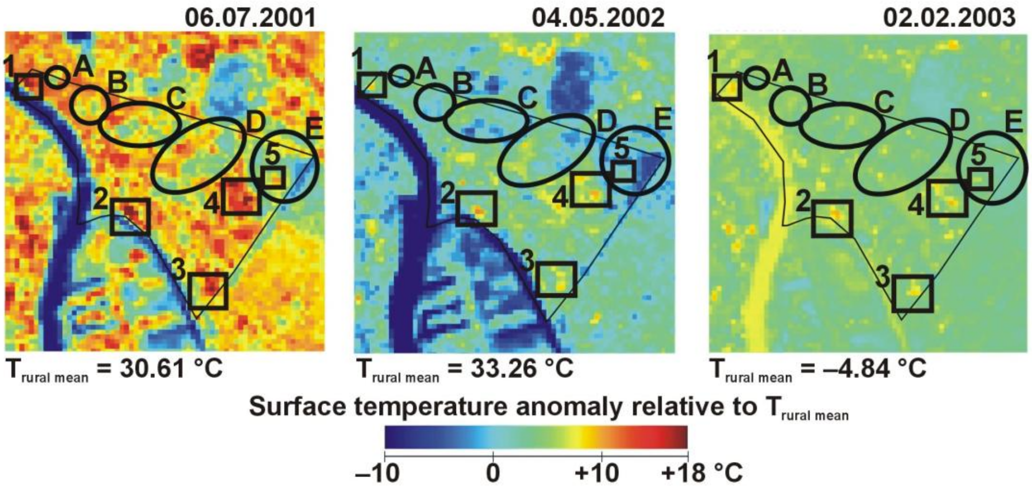


Fig. 4 Case studies for ASTER data. A, B, C, D, and E indicate cold spots, whereas 1, 2, 3, 4, and 5 indicate hot spots, detailed description can be found in Figs. 5 and 6, respectively.

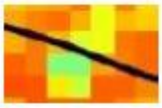
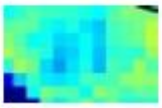
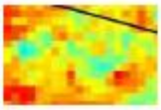
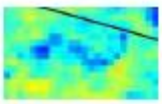
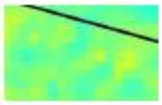
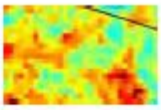
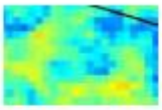
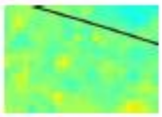
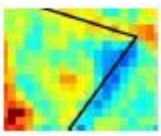
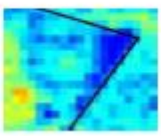
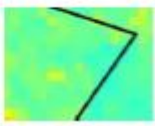
Google Earth Image	ASTER: 06.07.2001	ASTER: 04.05.2002	ASTER: 02.02.2003	Desription of the area for the period 2001-2003
 A	 ΔT: 6 – 7 °C	 ΔT: -1 – 0 °C	 ΔT: 3 – 4 °C	**Markusovszky square:** park to be developped
 B	 ΔT: 7 – 8 °C	 ΔT: 0 – 1 °C	 ΔT: 3 – 6 °C	**Ferenc square** park, with trees and grass area
 C	 ΔT: 4 – 6 °C	 ΔT: -5 – 1 °C	 ΔT: 3 – 6 °C	**St. Stephen and St. Laszlo Hospital:** park with trees
 D	 ΔT: 3 – 5 °C	 ΔT: -3 – 2 °C	 ΔT: 3 – 6 °C	**Merenyi Hospital, building community:** abandonned, non-properly maintained area
 E	 ΔT: -3 – 8 °C	 ΔT: -7 – 2 °C	 ΔT: 1 – 4 °C	Large, developped trees and green area within the **4-storey buildings community**

Fig. 5 Cold spots identified in the case studies of ASTER data.

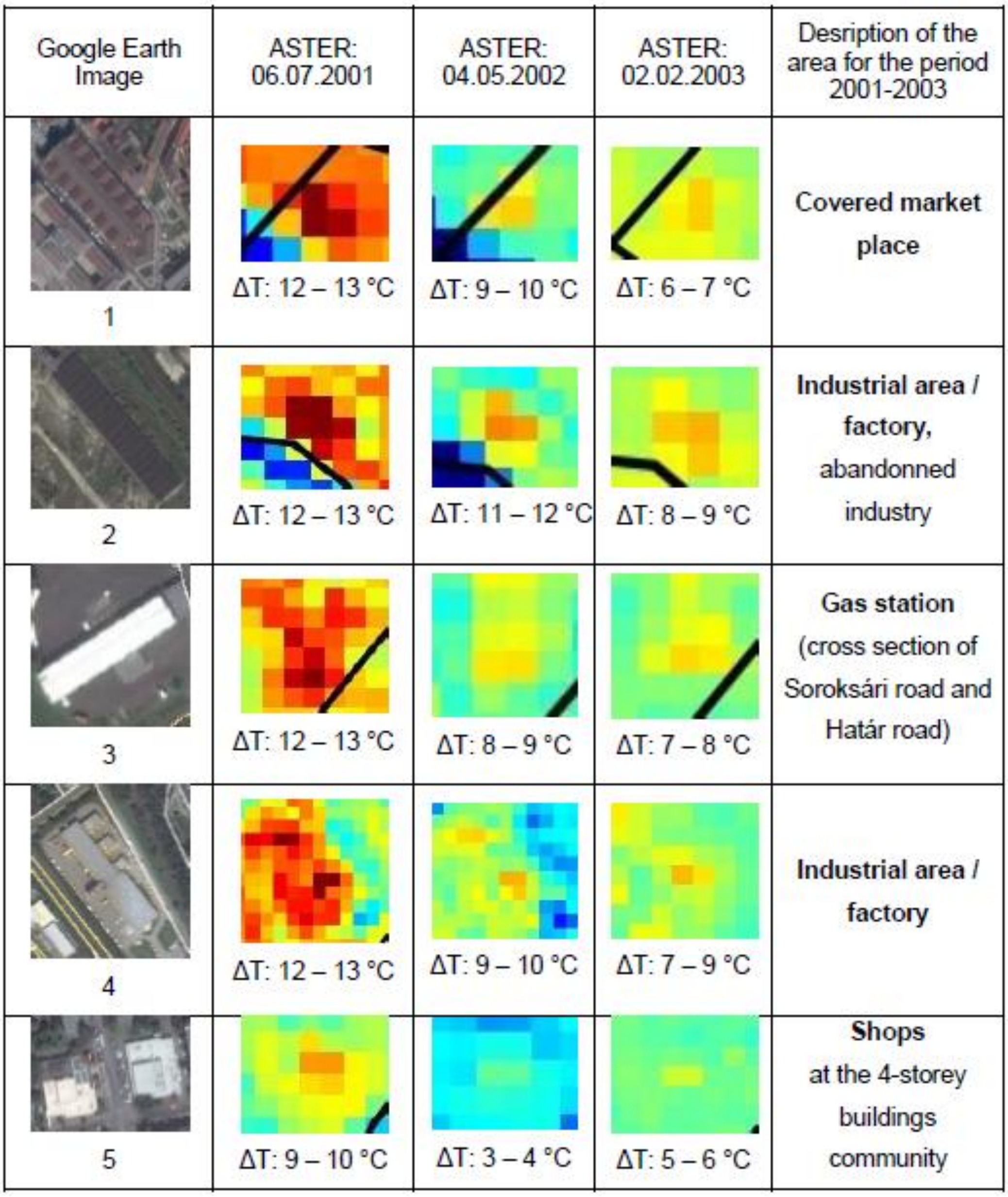


Fig. 6 Hot spots identified in the case studies of ASTER data.

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