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Analysing the urban vegetation effect using satellite imagery for Budapest

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1. Introduction

Budapest is the Hungarian capital, which is divided by the river Danube into a hilly, greener Buda side on the west, and the flat, more densely built-up Pest side on the east. Most of the extended urban vegetation can be found in the Buda side in the form of forests (BFO, 2011). The effects of these green areas are analyzed using surface temperature data calculated from measurements remotely sensed by MODIS (Moderate Resolution Imaging Spectroradiometer) in the infrared channels. The urban heat island effect of several Hungarian and Central European cities have been analysed in details (e.g., Dezso et al., 2005, Pongracz et al., 2006, 2010). Here, we aim to evaluate the surface temperature in the urban environment with special focus on vegetated-section of the city, the 12th distrrict of Budapest.

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. 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 (Terra, 1999; Aqua, 2002). Here, measurements of sensor MODIS (Moderate Resolution Imaging Spectroradiometer) are used. MODIS can be found on both satellites 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 the frame 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.

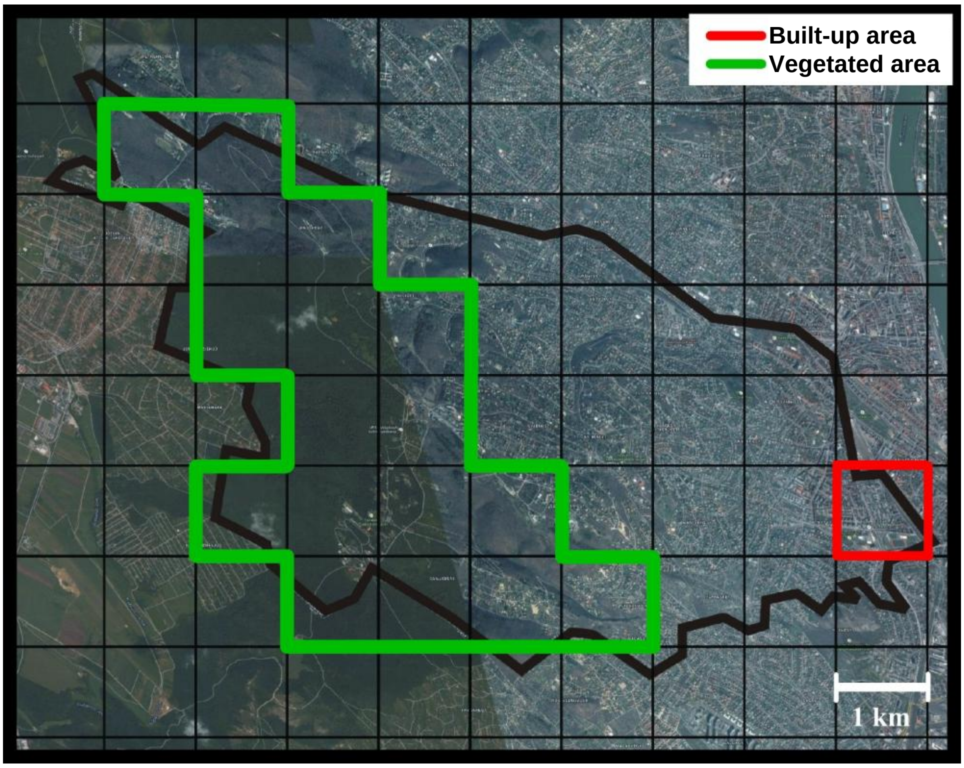

Fig. 1 Built-up and vegetated area of the 12th district of Budapest shown on the MODIS grid over the Google Earth satellite image.

In our research, we used the following MODIS products: Land Surface Temperature (LST), and Land Cover (Strahler et al., 1999). LST is determined by using the following channels: 3660-3840 nm (channel 20), 3929-3989 nm (channel 22), 4020-4080 nm (channel 23), 8400-8700 nm (channel 29), 10780-11280 nm (channel 31), 11770-12270 nm (channel 32), and 13185-13485 nm (channel 33) as described by Wan and Snyder (1999). In this paper, LST time series from 2001 to 2013 measured in the morning and late evening (in CET) by satellite Terra, and time series from 2003 to 2013 measured in the afternoon and before dawn (in CET) by satellite Aqua are analyzed. Therefore, two measurements are available daily for the 2001-2002 period, and four measurements for the 2003-2013 period. In order to cover the agglomeration area of the Hungarian capital within the Central/Eastern European region, the specific products are accessible via the Land Processes Distributed Active Archive Center (LPDAAC) at the U.S. Geological Survey.

SUHI (surface urban heat island) intensity values are calculated for each pixel within the 65×65 pixel representation of the Budapest agglomeration using the rural mean LST value for all available images (Bartholy et al., 2012). Then, the pixel representation of the most vegetated-covered district of Budapest is selected (Fig. 1). Monthly, seasonal, and annual averages of SUHI intensity are compared for the built-up and the vegetated pixels within the selected district.

3. Results and discussion

First, seasonal mean structure of the SUHI intensity is shown in Fig. 2. Since the selected subregion of the city is located at the western border, the SUHI intensity is the largest in the eastern part of the district, closer to the downtown area. The positive effect of the vegetation, i.e., less intense SUHI, is clearly visible in all the four seasons in case of all the four periods of the day. The inter-seasonal variance is larger in day-time (morning and afternoon) then night-time (evening and dawn) due to the definite annual cycle of the incoming solar radiation. The overall SUHI intensity difference within the district is the largest (8 °C) in summer during day-time (afternoon).

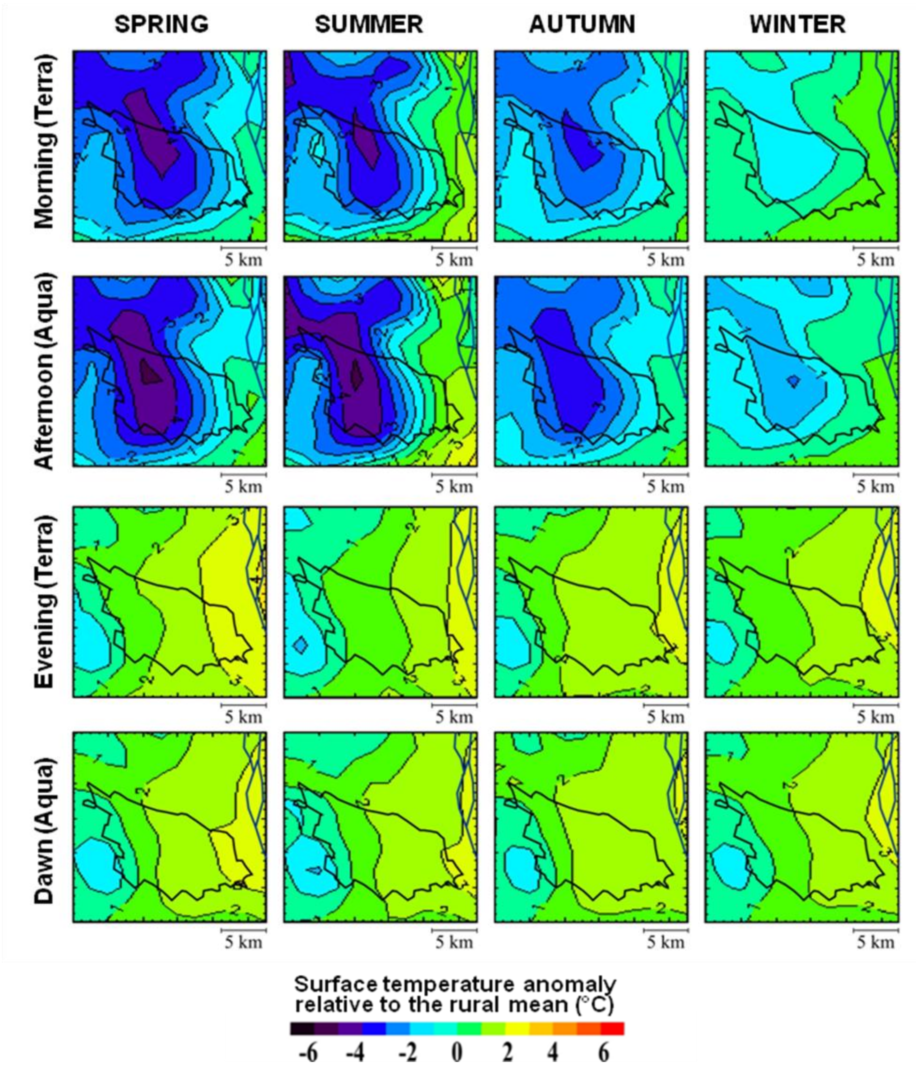

Fig. 2 Seasonal mean structure of the urban SUHI in the 12th district of Budapest, 2001-2013.

Fig. 3 compares the average annual cycle of the monthly mean SUHI intensity in the vegetated and the built-up areas during the four different periods of the day. The inter-monthly variation of SUHI intensity is clearly smaller during night-time than day-time, which is due to the fact the LST, and hence, SUHI intensity is mainly determined by the incoming solar radiation. Furthermore, in case of day-time the larger SUHI intensity in summer and winter, and smaller SUHI intensity in spring and autumn can also be identified in the built-up part of the district, whereas the largest cooling effect of the vegetation appears in the spring and summer months.

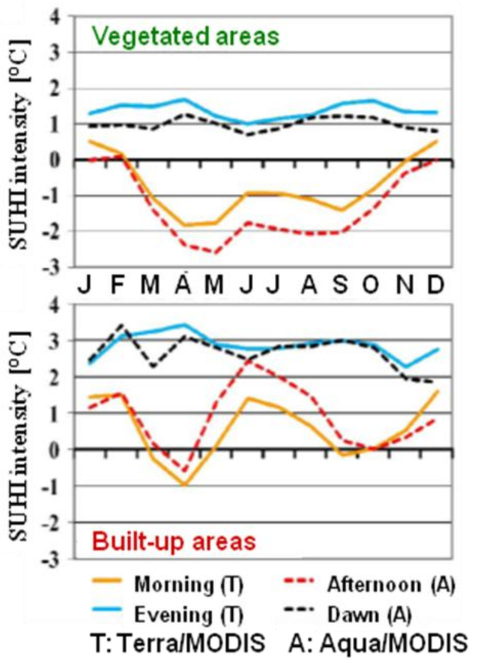

Fig. 3 Annual distribution of monthly mean SUHI intensity in vegetated and built-up areas of the 12th district of Budapest, 2001-2013.

Fig. 4 focuses on one day-time (afternoon) and one night-time (dawn) period of the day, and compares the SUHI intensity in the vegetated and built-up areas. The difference between the monthly mean SUHI intensity around dawn is about 1-2 °C throughout the whole year, whereas it is more variable at the afternoon: the difference is only around 1 °C from the late autumn to the early spring (when the green vegetation, i.e., the forest, loses most of the greenness due to the annual cycle of the continental plants), and increases to about 4 °C by June.

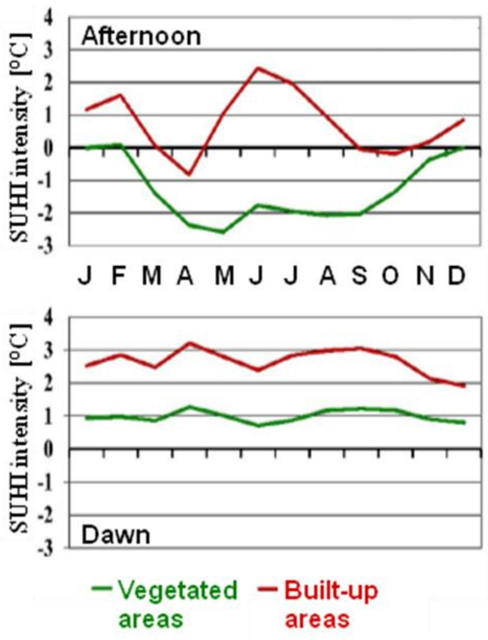

Fig. 4 Annual distribution of monthly mean SUHI intensity in vegetated and built-up areas of the 12th district of Budapest, 2003-2013.

Finally, Fig. 5 compares the trend analysis of monthly mean SUHI intensity values in the evening for both the vegetated and built-up areas. Slight increasing trend can be identified in both types of subregions for all the four months. The difference between the monthly SUHI intensity values are 1-2 °C, which can be considered as the overall effect of the vegetation.

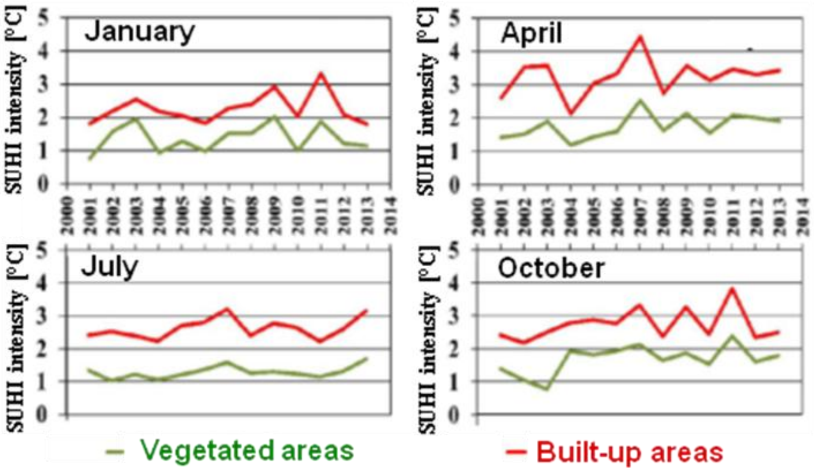

Fig. 5 Trend analysis of the monthly mean SUHI intensity in vegetated and built-up areas of the 12th district of Budapest, 2001-2013, based on Terra/MODIS measurements.

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