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COMPARISON OF URBAN HEAT ISLAND EFFECT USING GROUND-BASED AND SATELLITE MEASUREMENTS

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Summary – Human settlements (especially large urban areas) significantly modify the environment. One of the most often analyzed phenomena related to cities is the urban heat island (UHI) effect. In this paper, UHI intensity is compared using two different approach, namely, (i) satellite-based and remotely sensed surface temperature, and (ii) ground-based air temperature measurements using a moving vehicle. The analysis includes a comparison of annual and seasonal spatial structures, cross sections, as well as mean intensity values. Results suggest that the structures of UHI are similar using different techniques for both Debrecen and Szeged. However, the annual mean satellite-based UHI is more intense than the one calculated using mobile measurements.

Key words: urban heat island, mobile measurements, satellite measurements, MODIS, Szeged, Debrecen

1. INTRODUCTION

Urban areas have several significant impacts on the environment. For instance, the atmosphere is heavily polluted due to the industrial and road traffic emissions, therefore, severe smog events often occur over large agglomerations (Sokhi 1998), especially during long-lasting anticyclonic conditions. Furthermore, artificial covers (i.e., concrete, asphalt) considerably modify the energy budget of urban regions, and thus local climatic conditions. One of the most often analyzed phenomena related to cities is the urban heat island (UHI) effect (e.g. Sundborg 1950, Oke 1982). Besides several detailed studies of UHI using ground-based measurements (Moreno-Garcia 1994, Unger et al. 2001a), a more effective tool became available with the use of satellite imagery detected by different sensors on board. The early studies evaluated coarse resolution (7-8 km per pixel) satellite data (Rao 1972), and the applied methods to calculate surface temperature from spectral observations were very simple (Carlson et al. 1977, Price 1979). These investigations in the 1970s and 1980s concluded that satellite measurements can be applied to detect the UHI effect in case of clear conditions. Traditionally, UHI analysis (Howard 1833, Oke 1973) uses air temperature data observed at standard height (1.5-2 m above the ground), while satellite images provide thermal information at ground-level. On the basis of observed air temperature data, the maximum UHI intensity occurs a few hours after sunset, while the most intense UHI can be detected during day-time when remotely sensed data are used (Roth et al. 1989, Dezső et al. 2005). In this paper, UHI effects are compared for two large Hungarian cities (Debrecen and Szeged) using the above-mentioned two techniques.

2. DATA

For the comparison, satellite and ground-based measurements are used in order to determine the UHI for both Debrecen and Szeged.

In the case of the satellite data, surface temperature is calculated (Wan and Snyder 1999) from the day-time and night-time measurements of seven spectral bands of sensor MODIS (Moderate Resolution Imaging Spectroradiometer): 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). MODIS is a cross-track scanning multi-spectral radiometer with 36 electromagnetic spectral bands from visible to thermal infrared (Barnes et al. 1998), the horizontal resolution of the infrared measurements is 1 km. The sensor MODIS is carried on the board of the satellites Terra and Aqua, which were launched on 705 km height polar orbits in December 1999 and May 2002, respectively. Both satellites are part of the Earth Observing System Program of the American National Aeronautics and Space Administration (NASA). Remotely sensed data are available on a sinusoid projection. Based on these datasets, UHI effects are analyzed for the ten largest Hungarian cities in Bartholy et al. (2004, 2005), Dezső et al. (2005), Pongrácz et al. (2006a, 2006b), and the UHI of Central European large cities are discussed in Dezső et al. (2006), Pongrácz et al. (2008, 2009). The UHI intensity of Debrecen and Szeged is defined as the difference between spatial averages of urban and rural surface temperature.

The other approach using ground-based observations has been applied to Debrecen and Szeged. Mobile measurements were collected by data loggers when driving in the cities on a fixed predefined route, determined in order to optimally cover the inner and suburban parts of the cities. The study areas in both cases have been divided into 500 m × 500 m grid cells, and altogether 105 and 107 cells are used for Debrecen and Szeged, respectively (Unger et al. 2004). The 3-hour-long measurements on the 70 km long route were carried out between April 2002 and March 2003 at the same time in both cities. The mean of the measured temperature values has been calculated for each grid cell. The entire dataset consists of 35 temperature fields for Debrecen and Szeged. Detailed analysis of UHI in Szeged is discussed in Unger et al. (2001a, 2001b, 2004), Bottyán and Unger (2003), and the UHI of Debrecen is discussed by Kircsi and Szegedi (2003), Szegedi and Kircsi (2003), Szegedi (2005), Bottyán et al. (2005). UHI intensity for each cell is defined as the temperature difference relative to a rural reference point (which is set as the meteorological stations of the Hungarian Meteorological Service located in the suburban area of the cities).

Since the spatial resolution and the applied grid of satellite and ground-based measurements are different (Figs. 1 and 2 for Debrecen and Szeged, respectively), a transformation was necessary in order to accomplish the comparison. The grid of the satellite data is interpolated with a factor of 0.5, and for each cell of the 30 km long cross sections the closest grid point of the interpolated satellite grid is assigned (the cross section consists of 18 and 17 cells in the case of Debrecen and Szeged, respectively).

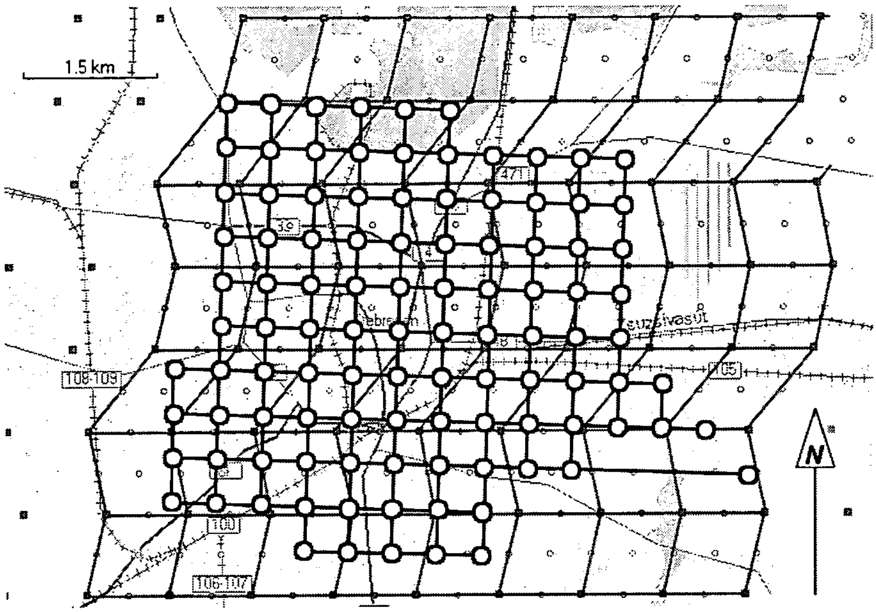

Fig. 1 Grid points of the ground-based (white circles) and satellite (dark squares) measurements in the case of Debrecen. Grey circles represent the interpolated grid points of satellite measurements.

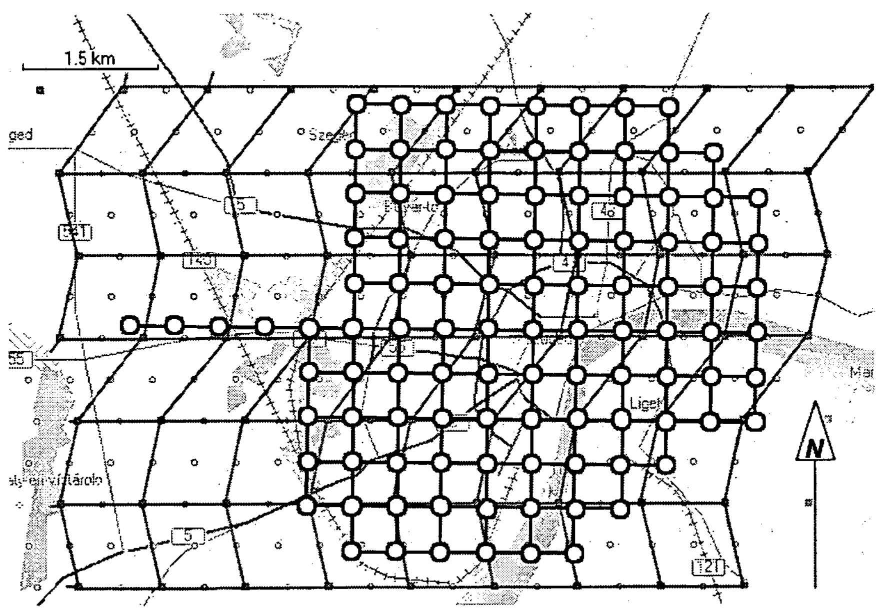

Fig. 2 Grid points of the ground-based (white circles) and satellite (dark squares) measurements in the case of Szeged. Grey circles represent the interpolated grid points of satellite measurements.

3. ANALYSIS AND RESULTS

First, UHI structure is determined for each date when data is available. In the case of satellite data, only temperature fields with clear conditions are used, therefore the comparison is made for 13 and 12 measurements for Debrecen and Szeged, respectively. The overall mean UHI structures based on satellite and mobile observations are shown in Fig. 3 for both cities. The spatial structures are similar, the most intense UHI is in the downtown area, but of course, the UHI map has finer resolution in the case of the mobile measurements. The satellite-based UHI is more intense both in Debrecen and Szeged. The difference is about 0.5-1.0°C.

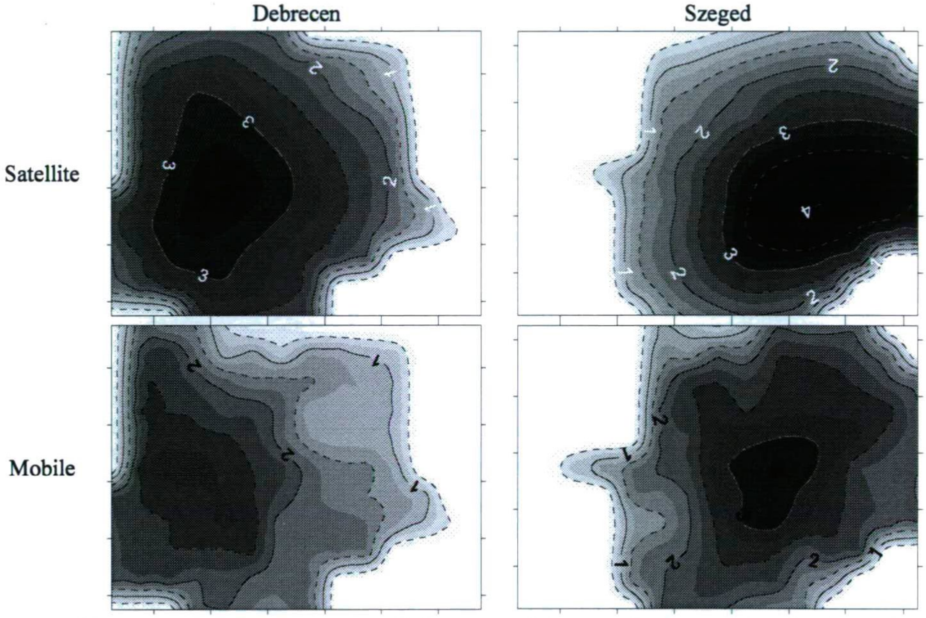

Fig. 3 Mean urban heat island structure of Debrecen and Szeged using ground-based and satellite measurements, 2002-2003. Isotherms are indicated in 0.5°C.

Fig. 4 compares the winter and summer mean UHI structures determined using the different temperature data for Debrecen, and similarly, Fig. 5 shows the results for Szeged. The winter UHI is usually more intense in the case of satellite-based temperature, it exceeds 4°C for Debrecen and 7°C for Szeged, while the mean ground-based UHI is only 2.5°C and 4.5°C, respectively. The opposite is valid for the summer means; the mean UHI is more intense in the case of the mobile measurements than the satellite data. In both cities the average maximum intensity exceeds 4°C when using the ground-based temperature measurements. Satellite-based mean summer UHI is less than 4°C in Szeged and 3°C in Debrecen.

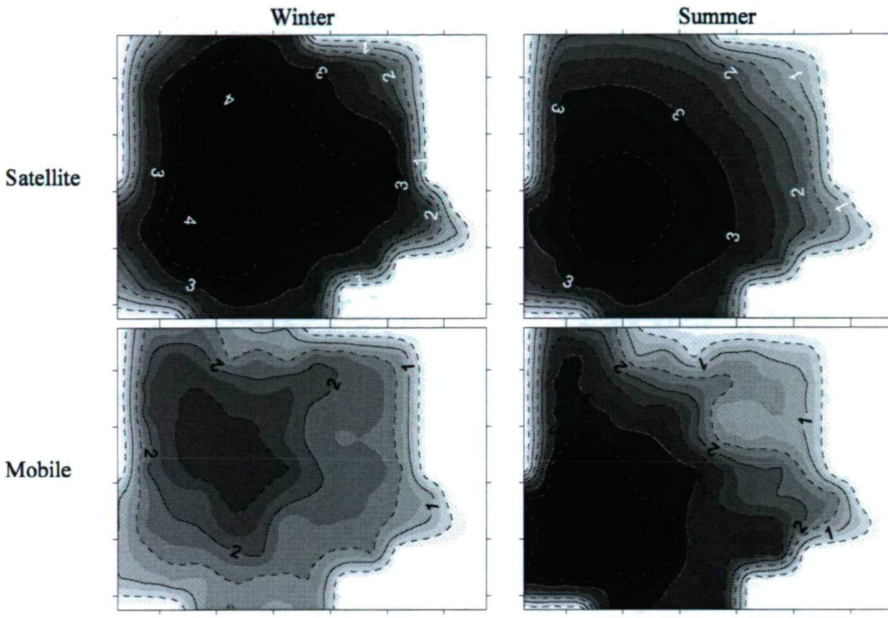

Fig. 4 Mean urban heat island structure of Debrecen using ground-based and satellite measurements, 2002-2003, winter and summer. Isotherms are indicated in 0.5°C.

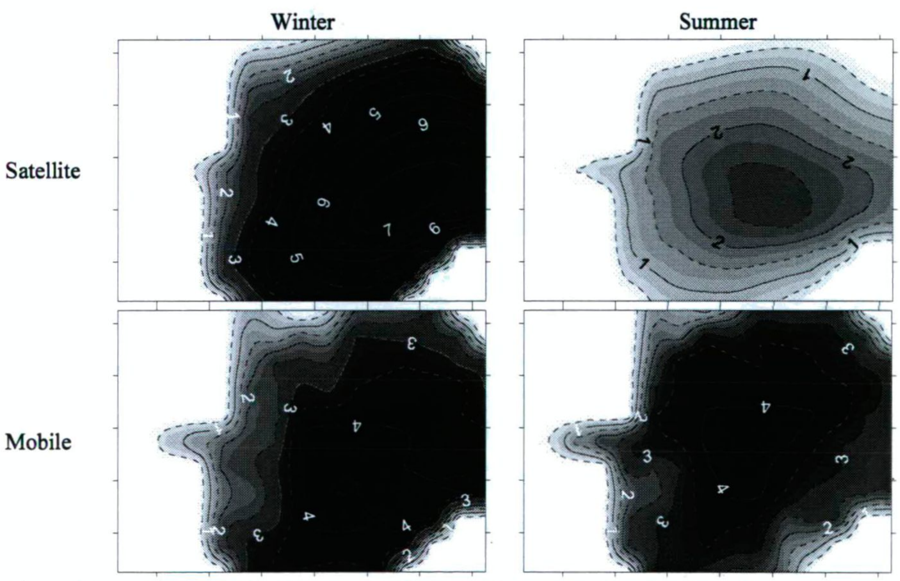

Fig. 5 Mean urban heat island structure of Szeged using ground-based and satellite measurements, 2002-2003, winter and summer. Isotherms are indicated in 0.5°C.

Mean UHI intensities along the characteristic cross-sections (Unger et al. 2001a) are compared in Figs. 6 and 7 for Debrecen and Szeged, respectively. In the case of Debrecen, the difference between the cell-wise UHI intensity is less than 1°C, the satellite-based UHI intensity is somewhat larger than the ground-based UHI intensity, except in the suburban areas of the city. The maximum intensity (around 3°C on average) can be detected in cell 12 for both techniques, which is located in the downtown area. In the case of Szeged, the differences between the two UHI intensity values are somewhat larger but still not exceeding 1°C. Differently from the UHI of Debrecen, the satellite-based mean UHI intensity in Szeged is smaller than if we use mobile temperature observations. The smallest difference (0°C) between the mean UHI intensity values is detected at or near the maximum, in cell 11 (located in the downtown area). Similarly to the UHI of Debrecen, the average maximum intensity exceeds 3°C in the case of Szeged, too.

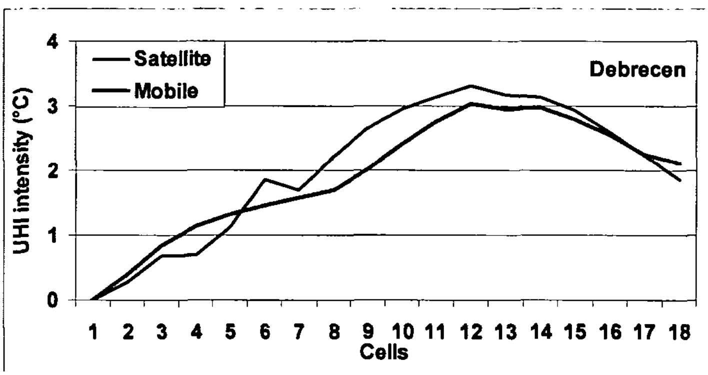

Fig. 6 Mean urban heat island intensity in the cross section of Debrecen using ground-based and satellite measurements, 2002-2003

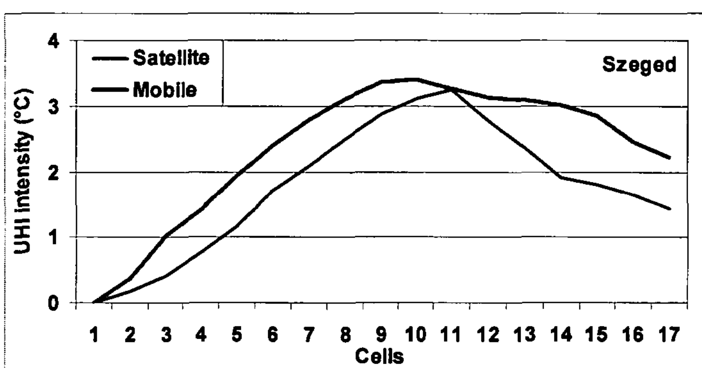

Fig. 7 Mean urban heat island intensity in the cross section of Szeged using ground-based and satellite measurements, 2002-2003

UHI intensity values at the locations of the maxima (using the satellite measurements) for each available dataset are compared in Figs. 8 and 9 for Debrecen and Szeged, respectively. In general, the satellite-based intensity is larger than the ground-based intensity, especially in winter. In Debrecen, the UHI intensity determined from satellite data is 3-6°C in February, while it is only 1.5-4.5°C when using air temperature values observed during mobile experiments. In Szeged, the difference between UHI intensity values is 3-4°C in February (satellite-based UHI is 6.5-7.5°C, and ground-based UHI is 3.5-4.5°C). In summer, differences between the two UHI intensity values are smaller (not exceeding 0.5°C and 1.5°C in the case of Debrecen and Szeged, respectively) than in winter for both cities. Furthermore, in some cases the satellite-based UHI is less intense than if mobile measurements are used to determine the UHI.

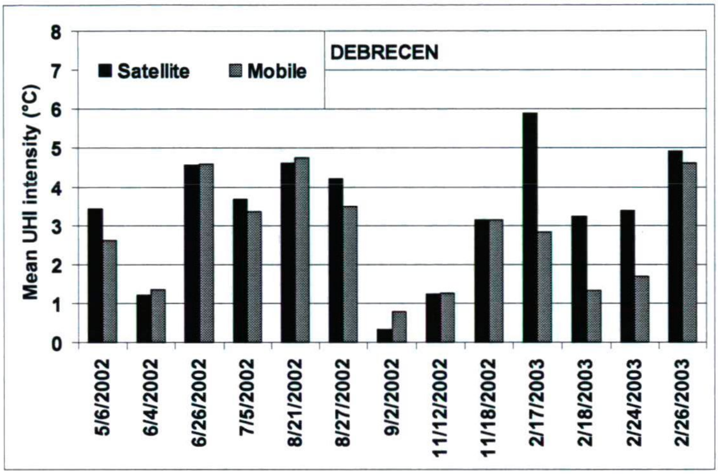

Fig. 8 Mean urban heat island intensity in Debrecen using ground-based and satellite measurements, 2002-2003

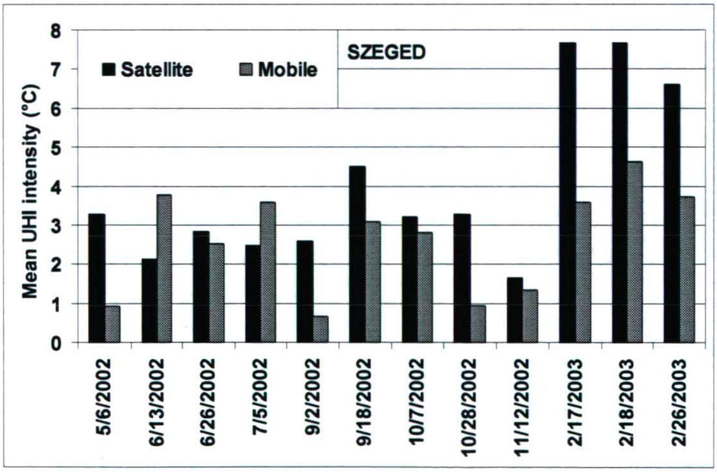

Fig. 9 Mean urban heat island intensity in Szeged using ground-based and satellite measurements, 2002-2003

4. CONCLUSIONS

Based on the results presented in this paper the following conclusions can be drawn.

(i) The spatial UHI structures using different techniques are similar in both Debrecen and Szeged. The most intense UHI can be detected in the downtown area, as expected.

(ii) The annually averaged satellite-based UHI is more intense both in Debrecen and Szeged (by about 0.5-1.0°C). Similarly, the winter UHI is also more intense in case of the satellite-based temperature. On the other hand, summer mean UHI is less intense when using satellite data than in the case of the mobile measurements.

(iii) Larger differences are detected between the UHI intensity values in winter than in summer for both cities.

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