AIR TEMPERATURE VERSUS SURFACE TEMPERATURE
IN URBAN ENVIRONMENT

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Abstract

The aim of our study to develop a method for the estimation of the early night-time near-surface air UHI pattern based on surface temperature data in Szeged, Hungary. The surface temperature data have been collected by airplane based thermal infrared sensor. The study area was covered by several hundreds of images with the spatial resolution of about 2 m. Simultaneous air temperature measurement was taken by car-based temperature sensor along a N-S urban transect. The data processing has taken with GIS methods, applying newly developed algorithms. In order to find the relationship between air and surface temperature a wider environment, the source area with a radius of 500 m was taken into account. As the results show the temperatures of the surfaces found in the surroundings (weighted by the distance) determine the temperature of the air parcel located at a given point. The obtained regression equation was applied to extend our results in order to model the air temperature field in a larger urban area.

Key words: urban environment, surface and air temperature, remote sensing

1. INTRODUCTION

The thermal features of settlements are different from their natural surroundings. As a consequence, a temperature excess develops in our living space in the near-surface air layer. This is the so-called 'classical' urban heat island (UHI), but, in addition, many kinds of UHIs can be defined. They include those defined according to the target medium, the location and the type of sensor (*Roth et al.*, 1989). These UHIs do not appear inevitably in an 'island' structure. Therefore in these cases it is more appropriate to talk about the urban temperature field or pattern.

The determination of the surface temperature (T_s) in cities is difficult because of the complex structure of the urban-atmosphere interface (*Voogt and Oke* 1997). In large urban areas it is usually measured indirectly by remote sensing technology however in this case the problem is that the camera does not 'see' the total active surface because of the obstructions present on the 3D surface (*Roth et al.,* 1989; *Soux et al.,* 2004).

The temperature of the air (T_a) among the buildings is affected by the temperatures of both horizontal and vertical surfaces (*Voogt and Oke* 1998). This multiple impact and the magnitudes of the effects of individual factors are very difficult to determine. *Voogt and Oke* (1997) introduced the concept of complete surface temperature which cannot be measured directly, but it can be calculated or estimated as a result of the radiation originating from all of the (horizontal and vertical) surfaces.

Roth et al. (1989) came up with the question of what the relationship is between surface and air temperature patterns. It is known that the nocturnal intra-urban variability in T_s is much smaller than the diurnal variability while the opposite is true for T_a. As the near-surface climates are directly connected to the active surface there seems to be a contradiction. According to *Roth et al.* (1989) this could be due to the following: (i) lack of simple connection between the T_s and T_a values (implied also by *Goldreich* (1985)), (ii) remote sensors do not perceive the full active surface, (iii) failure to recognize the different scales of climatic phenomena. As *Voogt and Oke* (2003) summarized, the relations between the two parameters remained empirical and no simple general relation was found but the correlations improved at night when microscale advection is reduced.

Our research is focussed on the area of impact which has an influence on the temperature of the near-surface air, presuming that a statistically based relationship can be established between the two temperatures if the size of this area is appropriately selected. Accordingly, the area of impact or *source area* is where the total impact of the physical features of its elements and their responses to the outer effects determines the temperature of a given air parcel. The aim of this study is (i) to compare the air and surface temperatures developing in a complex urban environment, (ii) to reveal the relationship between them applying different source areas and (iii) to generate an air temperature field for a large urban area with the help of the obtained relationship for two summer evenings with ideal weather conditions.

2. STUDY AREA, WEATHER SITUATIONS

Szeged is located in the south-eastern part of Hungary (46°N, 20°E) at 79 m above sea level on a flat plain (*Fig. 1*). The study area is located in the highly urbanized area of the city. In this area a large number of different land-use types are present (*Fig. 1*).

The observations of the University station located at the edge of the city centre were used to characterise the weather at measurement time and the preceding 36 hours. The insolation was undisturbed with maximum values of 810-860 Wm^{-2}, the wind speed (at 26 m above ground level) was moderate (0-4.7 ms^{-1}). The days were rather warm with maximum values of 28-36ºC and minimum values of 17-22ºC at dawn. Consequently, during the investigated period the weather conditions promoted the microclimatic effects of the surface features in Szeged.
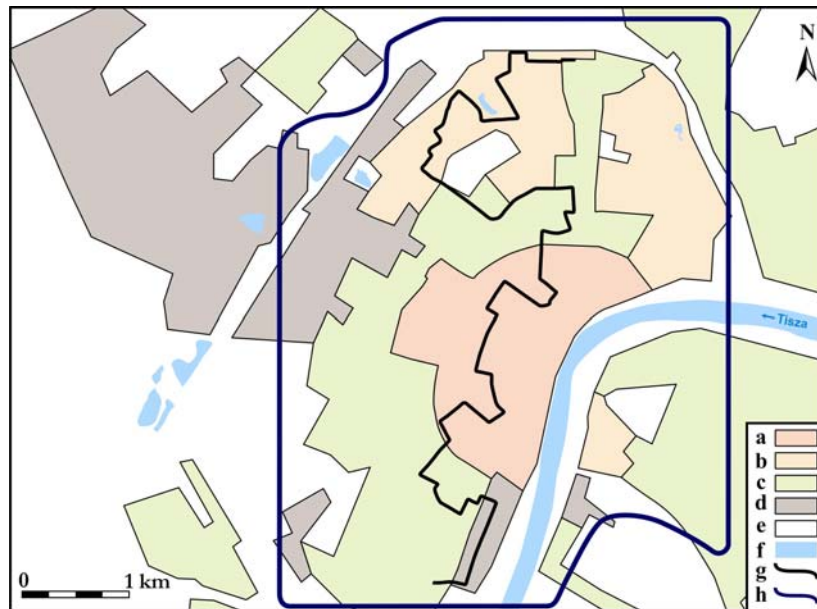

Fig. 1 (a) City centre, (b) housing estates, (c) detached houses with gardens, (d) industry and warehousing, (e) agricultural, green area, (f) river and lakes as land use types in Szeged; (g) measurement transect; (h) study area

3. METHODS

3.1. Temperature measurements

The measurements in 12 and 14 August took place in the 2-hour periods immediately after sunset. As sunset was at 19.57 LST (17.57 UTC), the airborne images were taken between 18.15 and 19.45 UTC, the surface and near-surface measurements were performed between 18.30 and 19.30 UTC. Thus 19.00 UTC is the reference time.

The air temperature observations were carried out by an automatic radiation-shielded sensor connected to a digital data logger that provided data at every 2 seconds. The sensor was located on a bar 0.6 m before the car and 1.45 m above the ground. The speed of the car was 20-25 kmh^{-1} and the data were gathered every 11-14 m (as well the GPS coordinates of these points).

The 11.8 km long measurement route is a N-S transect crossing the typical urbanized land use areas of the city. The one-hour measurements were taken there and back along the route in order to make time adjustments to the reference time assuming linear air temperature change with time at this period of the day. The route was divided by 15 m sections and then the averages of the mean values of the readings taken separately there and back on the 15 m long sections were computed (*Fig. 2*).
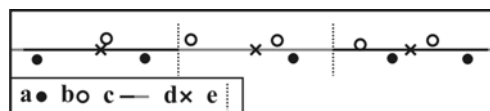

Fig. 2 An example on the spots of air temperature values regarded at the averaging (spots on (a) there and (b) back, (c) 15 m long sections, (d) section centres, (e) section borders)

The surface temperature measurements were carried out using an airplane based a small-format digital imaging system. The system is based on a FLIR (forward looking infrared radiometer) ThermaCam P65 thermal camera integrated with a navigation system and a GPS/GNSS receiver. To collect data at the required density, one image per 4 seconds was recorded while flying with a speed of 120 km at a height of 2000 m. The distance between the N-S transects provides the necessary overlapping area of 20-30%.

For the post-processing of the acquired thermal images in situ surface temperatures were necessary in order to transform the relative temperature scale to an absolute scale. They were measured directly by hand in 40 selected points representing the urban surfaces. After the calibration the images were combined to a single image, resulting in a thermal mosaic with a spatial resolution of 2.5 m, covering the complete survey area.

It was assumed that some lowering can be found in the surface temperatures during the flight times. If this dependence from the time is significant, the pixel values have to be corrected to the reference time of the survey according to the general cooling tendency. A statistically established trend was found only in the evening of 14 August. In order to refer the pixel values to the middle time these values were corrected by the obtained cooling rate: the values before the middle time were lowered; the ones after were increased.

The physical properties of the roofs constructed from metal considerably differ from the standard calibration values of the thermal camera. Highly reflective surfaces like aluminium, copper, or stainless steel work as a mirror resulting in false temperature measurements. The false temperatures were filtered out of the images.

3.2. Statistical method to reveal the relationship between air and surface temperatures

As mentioned in Section 1, the air temperature at a given point at 1.5 m a.g.l depends not only on the immediate surface under it and its own temperature. The T_a of this point is a result of the composite effects of the turbulent heat transports generated by the surrounding heated surfaces. Several studies looking for T_a−T_s relationship point out the importance of the micro-advection in the near-surface air layer (e.g. *Roth et al.*, 1989), which promotes the mixing of the thermal properties in a wider environment. Therefore, to investigate this connection a larger area and its thermal features have to be taken into account. According to the related literature, this source area covers an area with a radius of a few hundred meters around the measurement point, and in the case of calm weather it can be regarded as a circle. In urban environment, the circle has a radius of maximum 0.5 km for a temperature sensor at 1.5-2 m a.g.l, but this is likely to depend on the building density (*Oke* 2004).

These active surfaces are not only horizontal but also vertical (e.g. walls). In our case, only the temperatures of the horizontal surfaces can be detected on the thermal images, thus we can only use these temperatures in searching for the relationship between T_a and T_s.

For the determination of the size of the source area for the T_a values along the transect and the distance-based weighting of the pixel values inside it different approaches were applied, and only those are presented here which gave the best results. Some circles with a radius r (r = 100-500 m) around the points of T_a values were selected. The T_s pixel values of these circles were taken by weighting with a proportionality factor between 0.5 and 1. Thus the weighted and averaged surface temperature (T_s(wr)) regarding a given point's surrounding with a radius of r is determined by the next formula:

$$T_S(wr) = \frac{\sum_{i=1}^{n} T_{Si} \cdot \left(1 - \frac{D_i}{2r}\right)}{\sum_{i=1}^{n} \left(1 - \frac{D_i}{2r}\right)} \qquad [1]$$

where T_{si} is the i-th pixel value, D_i is the distance of the i-th pixel from the given point, and the summation refers to all pixels inside the circle with a radius of r. In order to automate this calculation for all points along the transect an algorithm was developed in the ArcView Avenue script language.

4. RESULTS AND CONCLUSIONS

According to the method described in *Section 3.2* several relationships can be obtained between the T_a values along the transect and the T_s(wr) values computed by [1] with different radius (two measurements, n = 1572). As *Table 1* shows the relationships are significant in all cases, however, the larger the radius the stronger is the connection between the two parameters. Since the best relationship is derived in the case of r = 500 m, henceforth the regression equation obtained in this case is applied to extend our results: to model the spatial distribution of T_a in a larger urban area in the case of the investigated two evenings.

Table 1 Relationships between T_s and T_a along the urban transect and their parameters regarding the surroundings with different radius r (R^2 – determination coefficient, R – correlation coefficient, σ_R − standard deviation around the regression line) at 12 and 14 August 2008 (n = 1572)

r (m)	Regression equation	R^2	R	σ_R	significance level
100	$T_a = 0.373 \cdot T_s(w100) + 17.691$	0.574	0.757	0.858	< 0.001
200	$T_a = 0.406 \cdot T_s(w200) + 16.898$	0.611	0.781	0.820	< 0.001
300	$T_a = 0.426 \cdot T_s(w300) + 16.453$	0.642	0.801	0.787	< 0.001
400	$T_a = 0.436 \cdot T_s(w400) + 16.228$	0.663	0.814	0.763	< 0.001
500	$T_a = 0.447 \cdot T_s(w500) + 15.982$	0.685	0.828	0.738	< 0.001

In the course of the extension of our results the surface temperatures in the whole study area were used as input data in a 100 m x 100 m mesh for modelling the air temperature fields in the evenings of 12 and 14 August. Since for computing T_s(w500) the pixel values around the mesh points (r = 500 m) are needed, the modelling area is ~ 21 km^2 (marked by blue line on *Fig. 1*).

The modelled air temperature field on 12 August has large areas with a temperature greater than 26.5ºC. This area is located in the city centre and streches out towards NW, where industrial and warehousing land use dominates (*Fig. 3a*). A temperature extension is present in NE direction where the large housing estates can be

found. The cooler areas of the low built-up districts, the outer green zones and the belt of the Tisza River and its banks (at NW, SW and SE) are also recognisable. On the whole, a difference of about 3ºC occurs in the area which is in accordance with the temperature range experienced along the transect in this evening (*Fig. 3a*).
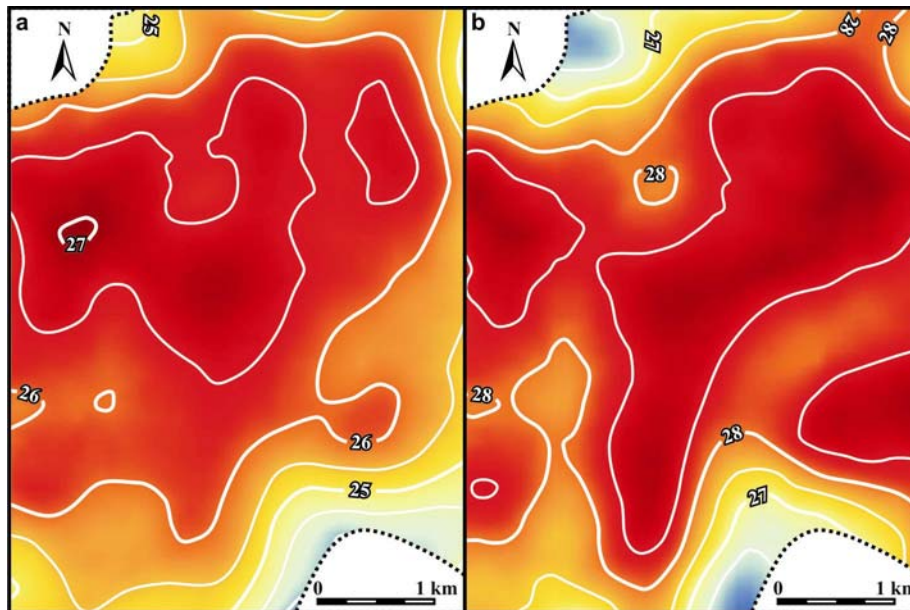

Fig. 3 Modelled air temperature patterns in Szeged at 19.00 UTC 12 (a) and 14 (b) August 2008
(location of the area is shown in *Fig. 1*)

The values of the modelled air temperature pattern on 14 August are higher than the values of the previous one (*Fig. 3b*). As on 12 August, basically the warmest (>28,5ºC) areas can be found in the centre, in the NW and NE parts, augmented towards S direction. Broadly speaking, the cooler areas are also the same. On the whole, also a difference of about 3ºC occurs in the area which is a bit lower than the temperature range measured along the transect of this evening (*Fig. 3b*).

So, we can conclude that the temperatures of the surfaces found in the surroundings (weighted with the distance) influence decisively the temperature of the air parcel located at a given point. The obtained regression equation can be applied to to model the air temperature field in a larger urban area.

By all means we should not forget that the obtained relationship is based on the data of only two, however complex, measurement campaigns. In the future, when using data of more measurements on days with similar environmental conditions to that of the investigated days, the result could be refined. Based on these new results we can make steps to the generalization of the operation mechanisms between the urban air and surface temperatures. In the frame of this study, a data collection in different seasons could also be a new direction, which can provide a possibility to examine the specific seasonal features and enable their comparison.

Acknowledgement

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