

The urban heat island of Bucharest during the extreme high temperatures of July 2007

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Abstract This paper explores the characteristics of the air (T_{air}) and land surface temperature (LST) from the city of Bucharest (Romania) during the extreme high temperatures that affected the region in July 2007. The behavior of Bucharest's Urban Heat Island (UHI) is quantitatively described following similar methodological approaches to previous studies. The analysis integrates thermal data supplied by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors aboard the NASA satellites and meteorological data provided by the ground-based weather stations. Based on the T_{air} , one may claim that during extreme high summer temperatures, the UHI preserves its spatial and temporal pattern regarding the differences between the central urban perimeter and the suburban area. The investigation of the LST from July 2007 reveals that the nocturnal changes refer mainly to the magnitude and the limits of the UHI, while the shape is not changed. However, the extreme temperatures induce significant modifications of the features of the diurnal UHI, obliterating and

dissipating it in certain spots, enlarging it and creating shifted heat islands in some other spots. The main explanation is the outstanding duration and intensity of the hot mass of air impacting the area. The correlations between the T_{air} measured at the weather stations in Bucharest and the corresponding LST retrieved significant values both under “normal” conditions and extreme temperature persistence, and offer good premises for robust validation studies. The MODIS products performed like an extremely useful instrument for analyzing the UHI.

1 Introduction

Extreme temperatures and heat waves are phenomena that may trigger considerable discomfort to society and environment. The large urban areas are among the most vulnerable to high temperature hazard: they amplify the magnitude of such phenomena, and they typically concentrate numerous population and assets. The heat wave that hit Europe in August 2003 left behind 35,000–50,000 casualties in the cities of the continent (United Nations Human Settlements Programme 2007). In the top ten world natural disasters of 2007 by number of victims, the European heat wave of July ranks the 5th, killing 567 persons in southern Europe and the Balkans (Scheuren et al. 2008).

In the last decades, numerous studies, thoroughly reviewed by Arnfield (2003), have approached various aspects regarding the Urban Heat Island (UHI). At the same time, emerging technologies like GIS and remote sensing found their valuable role in exploring the urban climate. Significant advances can be claimed (Jin and Shepherd 2005; Pongrácz et al. 2006; Hung et al. 2006), including recently the incidence of heat wave events in cities

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(Dousset et al. 2007). However, the perspective of using remote sensing in investigating the UHI was highlighted as early as the beginning of the 1970s (Rao 1972). The field has developed in the following years (Gallo et al. 1995), and Weng and Larson (2005) synthesize the current practice of using satellite remote sensing in UHI studies. Scholars like Dousset (1989), Dash et al. (2002), Jin et al. (2007), and Mendelsohn et al. (2007) argue that the satellite temperature measurements provide results better than the ones obtained by interpolating ground-station temperatures.

The temporal variations of the UHI are basically monitored on data provided by ground weather stations, recording suitable long-term series (Gaffin et al. 2008), but the satellite archives have accumulated an amount of data that can be also very useful. Acknowledging the deficiency of using short-term satellite datasets, one can still derive exploratory investigations to be pursued along with the ongoing augmentation of the available archives.

In general, on summer days, the air temperature (T_{air}) in a city can be 6–8°C higher than in the surrounding rural fields (Oke 1987). Tumanov et al. (1999) pointed out that the maximum intensity of the Bucharest heat island during the interval May–December 2004 was about 4°C. For the months of July 2000–2006, the maximum difference between mean hourly air temperatures in the city and its periphery was 2.9°C. This value reached 3.8°C in July 2007, while the whole area experienced one of the most stunning heat waves in its meteorological history. As a recent study explored Bucharest's UHI based on remote sensing images retrieved over the months of July 2000–2006 (Cheval and Dumitrescu 2008), we deem that a constructive approach would be to examine the behavior of the UHI during extreme high temperatures. This gives the opportunity to investigate the climatology of Bucharest's UHI between 2000 and 2007. The research is limited to this interval as it is covered adequately by both ground weather data and consistent remote-sensing images.

2 Objectives

The main objectives of this paper are: to investigate the characteristics of Bucharest's UHI during the unusual high temperatures in July 2007 (1), and to survey the potential of the MODIS satellite images to provide useful information for such approaches (2). Furthermore, the study compares the characteristics of Bucharest's UHI during the extreme temperatures in July 2007 to its average features over the months of July 2000–2007.¹

¹ Hourly temperatures for 2000 are not available at București-Afumați

The research is conducted based on two types of data exploited both individually and comparatively: one dataset provided by meteorological stations and the other one retrieved by satellite images. The spatial coverage of the temperatures derived from satellite images is considerably significantly greater for analyzing the UHI than in the case of weather stations. However, one has to take into account that the information is fundamentally different. The satellite data are derived from an area with a surface equal with the resolution (1 km in the case of the MODIS products used here), whereas the station data are discrete measurements. Besides, the satellite images return the radiant surface temperature, and the weather stations provide the air temperature measured at 2 m. The results of a comparison between the two types of information should be realistically manipulated (Wang et al. 2008).

We analyzed the UHI in terms of its magnitude, extension, and geometry, and we also scrutinized its temporal and spatial evolution in the interval 2000–2007.

3 The climatologic background and the general thermal characteristics of July 2007

The city of Bucharest is situated in the central part of the Romanian Plain, at the intersection between 44°30' N and 26°00' E, with general elevations of 80–120 m. It has a temperate climate, influenced mainly by the alternate or simultaneous influence of the Western circulation, the East-European Anticyclone, the Mediterranean Cyclones, and the Tropical advections. The annual mean temperature (1961–2006) is 11.3°C. January is the coldest month (−1.5°C) and July is the hottest (22.9°C). Bucharest has a permanent population of around 2 million inhabitants, and it stretches over a surface of about 240 km². Its climate is monitored by three weather stations operated by the Romanian National Meteorological Administration (Fig. 1): one inside the city limits, namely București-Filaret (B-Filaret), and the others at its northern and north-northeastern peripheries, namely București-Băneasa (B-Băneasa) and București-Afumați (B-Afumați).

In the whole area, during the month of July 2007, temperatures were exceptionally high. Hot air masses persisted over the whole Europe for significant long spells, and the deviations from the multiannual mean temperatures were positive over Romania (Fig. 2). They reached extremely high values in its southern part, the hottest day being 23 July (Fig. 3).

In 86% of the days, the maximum T_{air} in the city surpassed the long-term daily averages: 15 values were above 35°C and four values were higher than 40°C (Fig. 4). The overrunning of the multiannual average was exceptional: it ranged within 4–12°C in almost 70% of the cases,

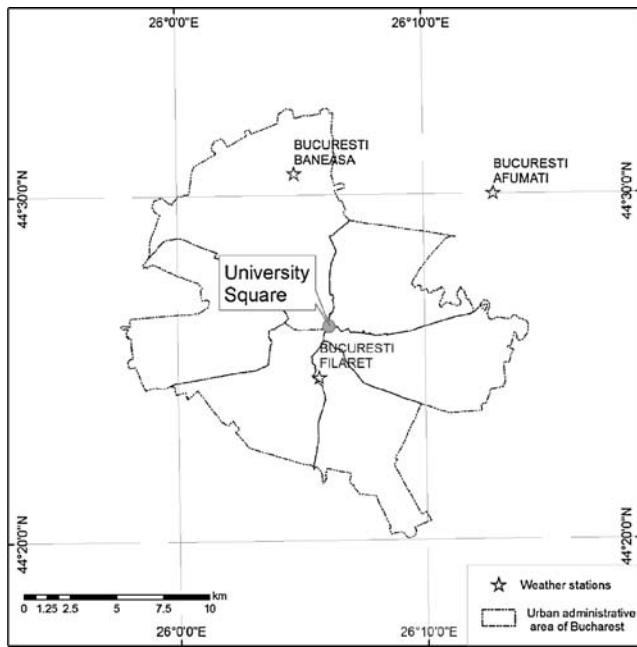


Fig. 1 The position of the weather stations that monitor the climate of Bucharest

8–12°C in almost 30% of the cases, and the longest heat spell duration was 16 days (15–30 July 2007). In their turn, the hourly air temperatures in July 2007 were considerably higher than the 2000–2007 average (Fig. 5). There is still a

weak UHI signal during the night (00.00–04.00 UTC) when the atmosphere stabilizes (the surface is cooling, and the warm air floats above) and surface winds consequently weaken.

4 Methodology

This research integrates thermal data provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors aboard the Terra (EOS AM) and Aqua (EOS PM) NASA satellites, and meteorological data supplied by the ground-based weather stations operated by the Romanian National Meteorological Administration.

The Land Surface (or Skin) Temperature (LST) in the Bucharest urban perimeter is compared with the rural surrounding area for night and for daytime. The LST was derived from the MODIS satellite images available for July 2000–2007. Two MODIS products, MOD11_L2 and MYD11_L2, supply instantaneous views of the LST, at a 1-km resolution, twice a day each (two night and two daytime images) and they were used consequently for deriving the UHI of Bucharest. The satellite-derived LST is controlled by objective factors (e.g., cloudiness, blurry atmosphere), so that we selected 765 images from the July 2000–2007 ones (398 for day and 367 for night) that have at least one pixel with LST

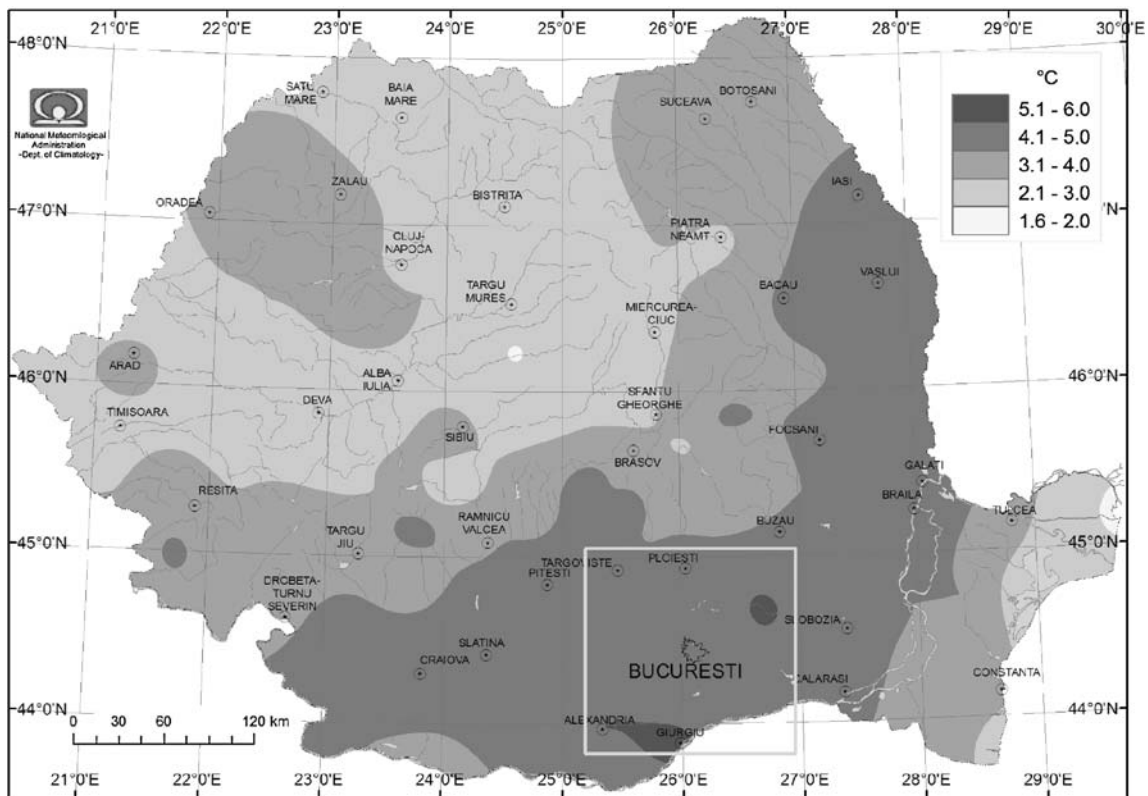
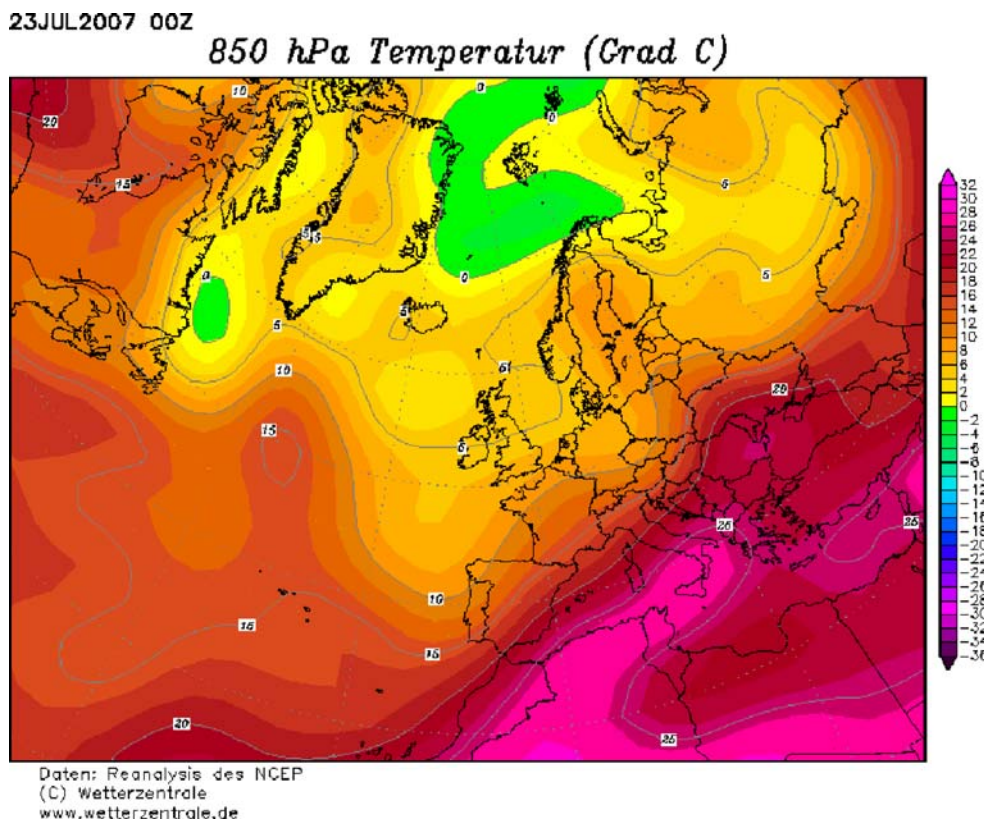


Fig. 2 Deviations of the air mean temperatures in July 2007 from the multiannual averages of July

Fig. 3 European thermal context at 850 hPa on 23 July 2007



registered in the administrative perimeter of Bucharest. Daytime images cover the interval 08.05–12.40 UTC,² and nighttime images are retrieved between 18.45 and 01.55 UTC.

General information about MODIS is currently available³ and many sources supply technical details on the products and their application in LST studies. It has to be mentioned that the brightness temperatures and the surface emissivity are incorporated in the algorithm of the MOD11_L2 and MYD_L2 products. Dash et al. (2002) provided a theoretical basis and an overview of the research dedicated to the retrieval of the LST from passive sensor data. More specific technical details on the products MOD11_L2 and MYD11_L2 can be extracted from committed Web sites.^{4,5} Wan et al. (2004) documented that in clear sky conditions at a 1-km resolution, the MODIS LST accuracy is higher than 1°C in the -10 to 50°C range, attesting its proficiency for studying the UHI of large cities.

Considering *Piața Universității*⁶ as the center of the Bucharest’s UHI (Cheval and Dumitrescu 2008), the LST

was analyzed along 16 transects, 30 km long each (Figs. 1 and 6). The shifting points returned by the Rodionov test (Rodionov 2004) were considered the limits of the UHI for each transect. This method assumes that each data point is independent of the other measurements, so that there is no serial correlation; at the same time, the method is based on the sequential application of Student’s *t*-test, used in the spirit of exploratory, rather than confirmatory, data analysis (Rodionov 2005).

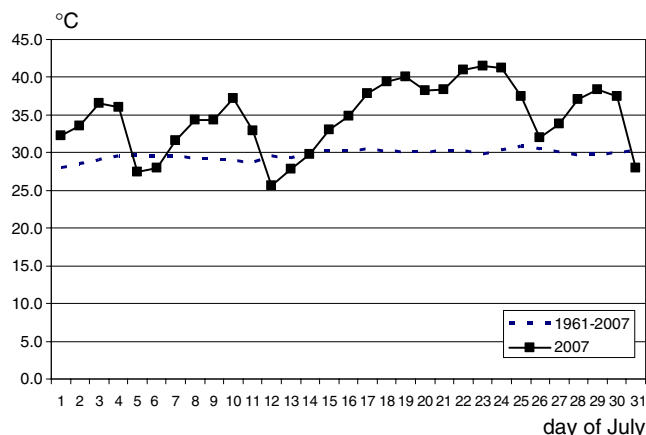


Fig. 4 Daily maximum air temperature in July 2007 and multiannual maximum temperature (1961–2007) at B-Filaret

² In July, the sun raises at 02.35–03.01 and sets at 18.03–17.41 UTC. The Bucharest local time is UTC+3.

³ <<http://modis.gsfc.nasa.gov/>>

⁴ <http://edcdaac.usgs.gov/modis/mod11_l2v4.asp>

⁵ <http://edcdaac.usgs.gov/modis/myd11_l2v4.asp>

⁶ University Square (ro.)

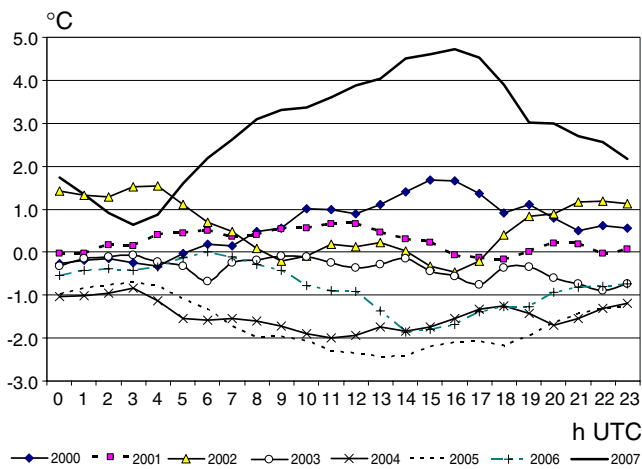


Fig. 5 Deviations of the hourly average air temperatures in the months of July 2000–2007 against the multiannual average 2000–2007, aggregated for the three stations of Bucharest

Based on a previous analysis of the Bucharest’s UHI using MODIS images (Cheval and Dumitrescu 2008), the satellite raw products were filtered twice. First, the data placed beyond the interval ($ave \pm 2 * stdev$), where *ave* is the average and *stdev* is the standard deviation calculated for each pixel of the cross-profiles, were eliminated. Second, the same filter was applied for each transect and for each image, removing the extreme values that might have artificially biased the results.

A distinct dataset refers to the air temperature. Hourly values were provided by the weather stations B-Filaret, B-Băneasa, and B-Afumați for different periods, mentioned whenever used. The T_{air} was analyzed both separately and in comparison with the LST.

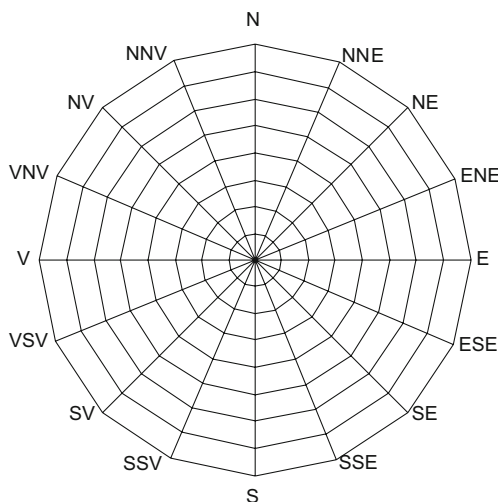


Fig. 6 Transects allocation

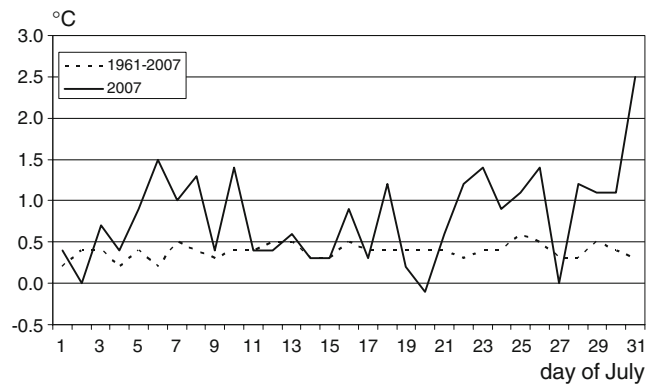


Fig. 7 Differences between the daily average maximum temperatures at B-Filaret and B-Băneasa weather stations in the months of July 1961–2007 and in July 2007

5 Results

The results draw attention to the effects of the extreme high temperatures from July 2007 on the UHI based on T_{air} (1) and LST (2), and present an exploratory comparison between the T_{air} and the LST (3).

5.1 Influences of the extreme high temperatures of July 2007 on the Bucharest’s UHI

The average differences between the maximum daily T_{air} downtown Bucharest and its outskirts are less than 0.5°C in 30 days, in July 2007. The difference exceeded the multiannual average in 77.5% of the days, it was higher than 1.0°C in 12 days and it reached 2.5°C in the last day of the month (Fig. 7).

Referring to the July hourly regime, the highest values of the average differences between the T_{air} downtown Bucharest and periphery occur during the nights, and the lowest at 5–7 UTC. In July 2007, they exceed 1°C in 46% of the terms,

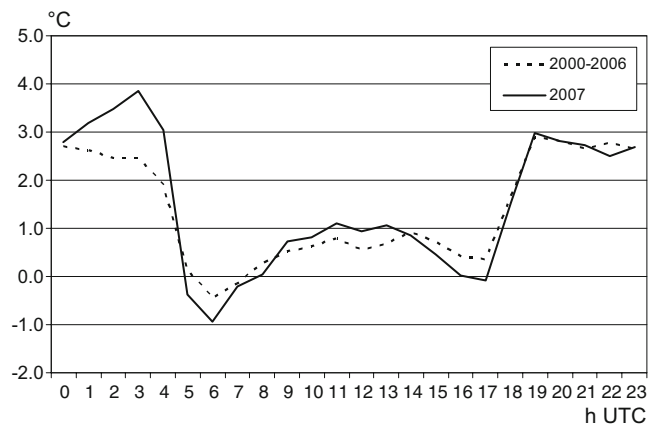


Fig. 8 Differences between the hourly average temperatures at B-Filaret and B-Băneasa weather stations in the months of July 2000–2006 and in July 2007

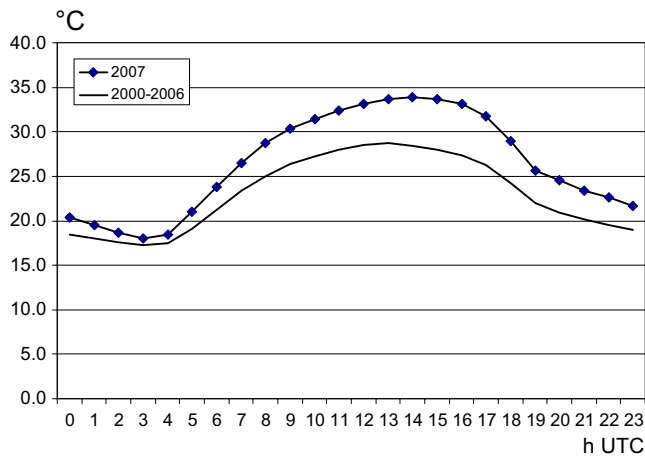


Fig. 9 Hourly average temperatures in July 2007 against the average July 2000–2006 aggregate of the three weather stations in Bucharest

but the multiannual pattern was largely preserved (Fig. 8). The differences were much exacerbated at their multiannual high level between 2 and 4 UTC, showing an intensification of the morning UHI. The urban heat storage accumulated during the daytime in July 2007 was higher than in an average July and its evacuation by radiative cooling is consequently slower.

The hourly average temperatures of July 2007 surpassed the multiannual averages for all the instances, but the maximum values are shifting from 13 to 14 UTC (Fig. 9).

The deviations against the 2000–2006 average emphasize a distinct diurnal pattern at all Bucharest stations (Fig. 10). The highest values are recorded in the evening (5–6°C at 17–20 h, local time) and the lowest at the daybreak (0.3–2.0°C at 5–8 h, local time). As the city accumulated more heat under the extreme hot weather conditions of July 2007 than in usual summer days, the

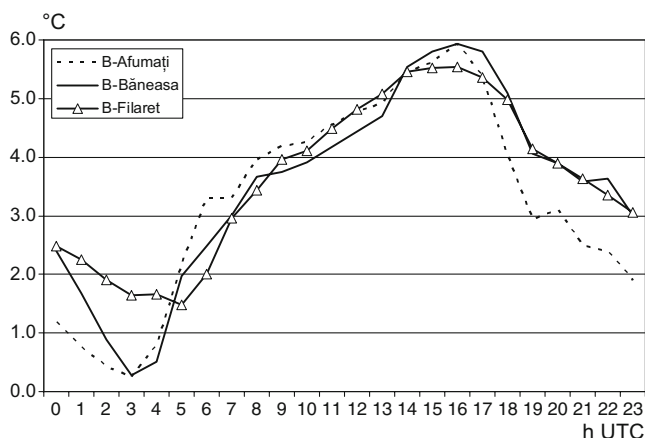


Fig. 10 Deviations of the hourly average air temperatures in July 2007 against the average July 2000–2006

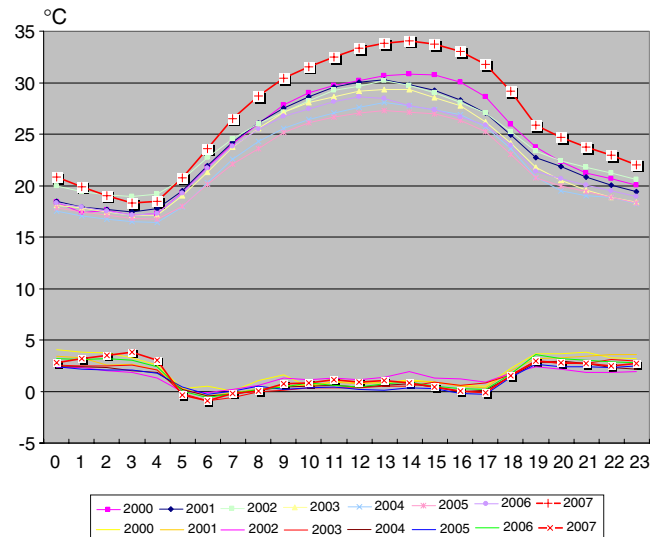


Fig. 11 Hourly temperatures in July 2000–2007: the *upper lines* are the averaged values from B-Filaret and B-Băneasa weather stations and the *lower lines* are the differences between them

thermal demarcation between the urban and suburban stations became slightly more pronounced at night, when it already is at its peak.

The thermal amplitude between downtown and periphery is in a reversed relationship with the absolute value of the air temperature over the city ($r=-0.62$), and the heat spells do not induce significant changes in this relationship (Fig. 11). Moreover, in July 2007, most of the time the downtown temperature (B-Filaret) and the suburban one (B-Băneasa) exceeded their corresponding averages with similar values (Figs. 8 and 10).

The results indicate that in summer, during extreme high temperatures, the spatial and temporal pattern of the UHI and its magnitude do not vary significantly.

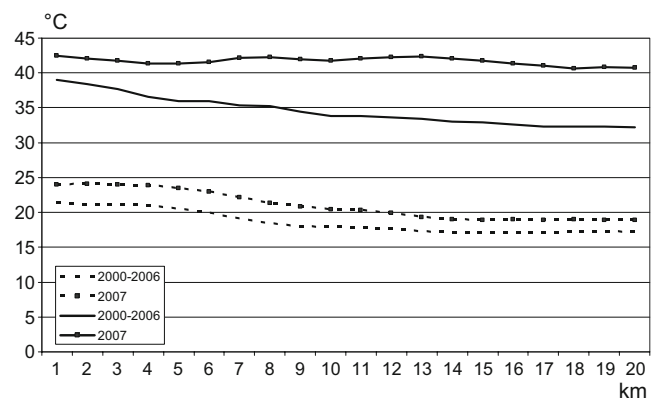
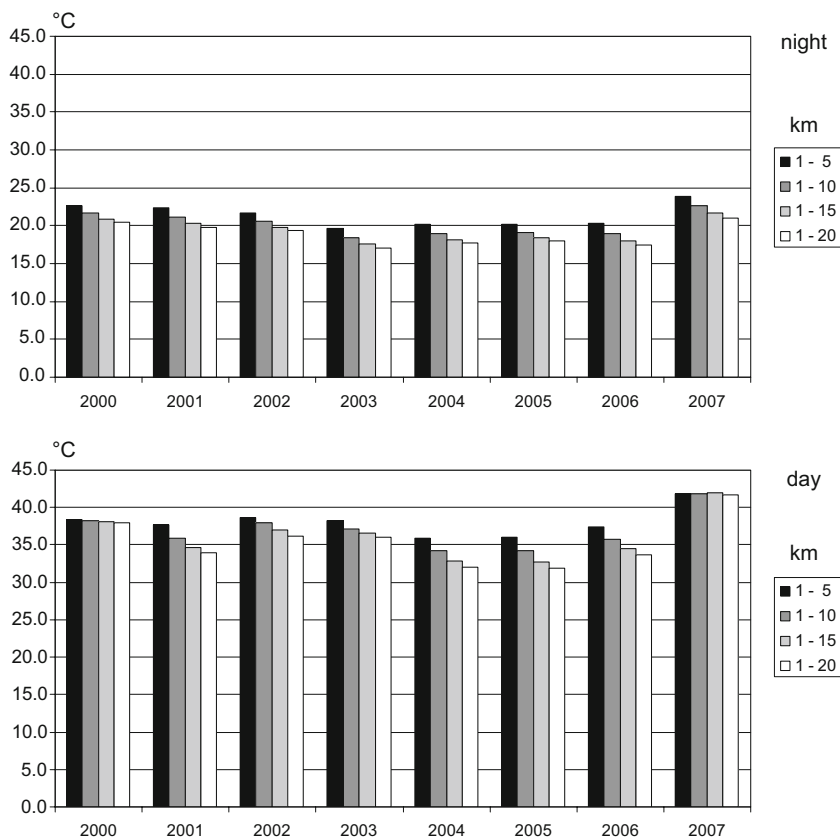


Fig. 12 Average land surface temperatures at different distances from University Square averaged for the 16 transects, for day-time (continuous line) and night-time (interrupted line)

Fig. 13 Land-surface temperatures for different patches around *Piața Universității* averaged for the 16 transects



5.2 Bucharest’s Urban Heat Island in July 2007, as derived from MODIS images

Figure 12 shows the July LSTs derived from the MODIS images at different distances from University Square, averaged for the 16 transects. The night values in 2007 and those averaged over 2000–2006 differ only in magnitude. In July 2007 the shape of the global transect was modified, and the diurnal values do not indicate the presence of the UHI.

Generally, both for day and nighttime, the July LST diminishes with the distance from the city center, but the land cover may locally reverse this trend (Cheval and Dumitrescu 2008). Here we found that in 2007, the hottest in the period, the daytime values remained quasi-identical over buffers of 5, 10, 15, and 20 km around University Square. A similar pattern is observed for the year 2000, and to a certain extent, 2002 and 2003, ranked the 2nd, 3rd, and 4th warmest years, respectively (Fig. 13). Furthermore, we identified a significant, negative correlation between the daytime LST averaged over the first 10 km of the 16 transects and its amplitude calculated in the first 20 km around the center of Bucharest, while the nocturnal correlation is negligible (Table 1).

The heat waves apparently obliterate the UHI by reducing dramatically the diurnal differences between the urban and the rural temperatures and less evidently the nocturnal ones (Fig. 14). The high surface temperatures lead to unstable conditions and a higher mixing layer, with deep convective mixing and associated heat transport, minimizing or dissipating the diurnal UHI (Camilloni and

Table 1 Land-surface temperatures in July averaged for the 16 transects over 10 km around University Square (Ave10), the LST amplitudes calculated for the 20 km around University Square (Ampl20) and correlation coefficients ($p=0.1$)

	Night		Day	
	Ave10	Ampl20	Ave10	Ampl20
2000	21.7	6.0	38.2	9.9
2001	21.2	6.5	35.9	13.4
2002	20.5	7.8	38.0	15.2
2003	18.3	7.3	37.2	13.2
2004	19.0	6.6	34.2	14.5
2005	19.1	6.1	34.2	15.8
2006	19.0	7.1	35.8	15.1
2007	22.7	8.0	41.9	11.9
Correl Ave10-Ampl20	0.19		-0.61	

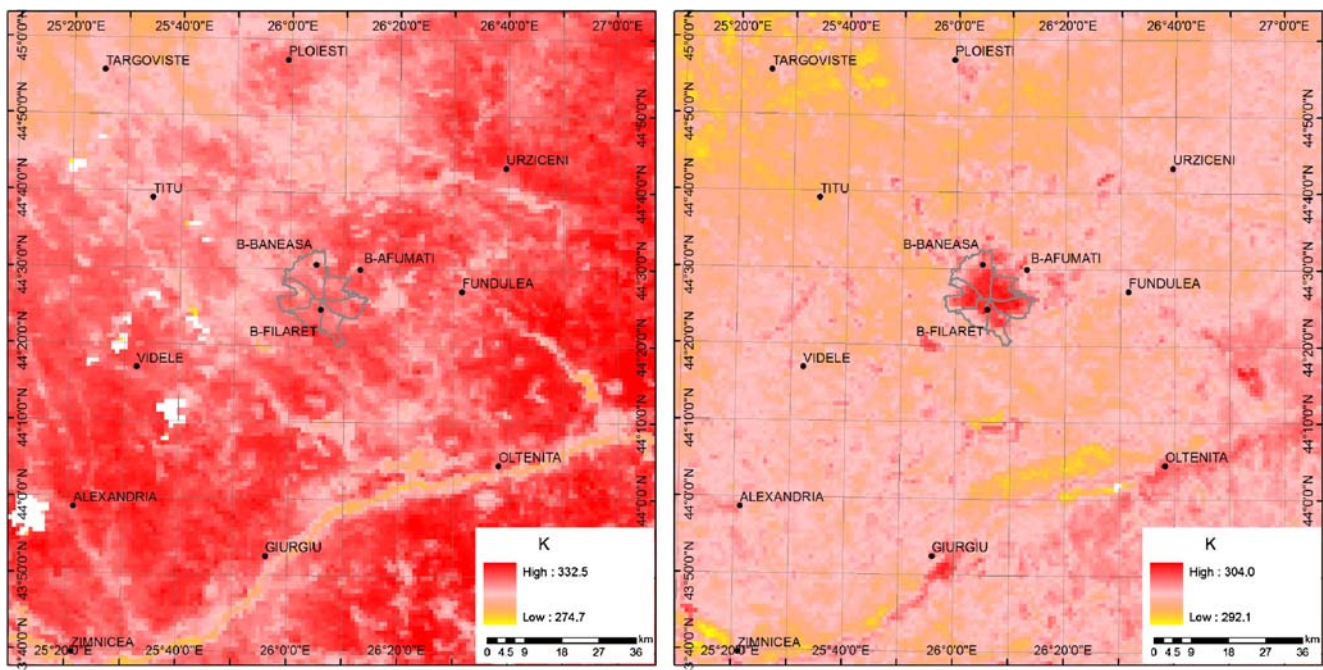


Fig. 14 LST in the central part of the Romanian Plain on 23 July 2007, at 09.05 UTC (*left*) and 20.00 h UTC (*right*), as retrieved from the MODIS product MOD11_L2

Barros 1995). Analogous results, namely “a significant nocturnal heat island in downtown related to the built density and lack of evapo-transpiration and multiple daytime thermal anomalies scattered over the industrial suburbs related to low thermal inertia and unobstructed field of view”, were obtained by Dousset et al. (2007) while analyzing the 2003 Paris heat wave. Besides, the evaporation cooling in rural areas decreases with the length of the heat waves due to less surface moisture available, so that the horizontal thermal gradient diminishes.

Mapping and comparing the LSTs of the months of July 2000–2006 and 2007, one may remark that the UHI is qualitatively apparent by night, while its day-time manifestation is very deficient in the extreme high temperatures of 2007 (Fig. 15).

Furthermore, in order to explore quantitatively the characteristics of the UHI, we first delineate its average limits for 2000–2006. For each transect, the shifting points delivered by the Rodionov test (Rodionov 2004) were considered the limits of the UHI. The shifting points computed here are a little different compared to the results of a previous experiment (Cheval and Dumitrescu 2008) for three reasons: the datasets were filtered in a different way (1), they cover diverse time intervals (2) and the parameters of the Rodionov test were changed (3). The new parameters are designed to avoid the identification of false shifting points by strengthening the level of confidence and by testing and aggregating various cutoffs. Nevertheless, taking into account the mentioned differences, and since

there is no expectation to establish inflexible UHI limits, the results proposed by the two experiments are remarkably similar (Table 2). For nighttime, 70% of the instances are identical, and only in one case the difference between *Exp1* and *Exp2* exceeds 1 km, while for daytime, *Exp1* and *Exp2* have returned equal results in 81% of the cases and variations above 2 km in only two cases. All the differences derive largely on the too-relaxed level of confidence adopted for *Exp1*.

Subjected to the same methodological procedure and compared with the averages exposed in Table 2, the LST and the consequent UHI of July 2007 are notably different due to the particular thermal conditions of the period. In most of the cases, for night and mainly for daytime, the Rodionov test identified 2–3 shifting points in the built/administrative area or in its vicinity, making it very difficult to fix on the limits of the UHI (Fig. 16). Even though the level of significance was relaxed to 0.1, the results were ambiguous.

5.3 Comparing MODIS LST and ground measurements as a support for UHI studies

MODIS provides a continuous spatial coverage, but decennial archived data is not yet available. Long-term data from the Bucharest weather stations are available, but it is not possible to detect a consistent urban temperature gradient with data from only one urban and one suburban station. The comparison is further complicated by the

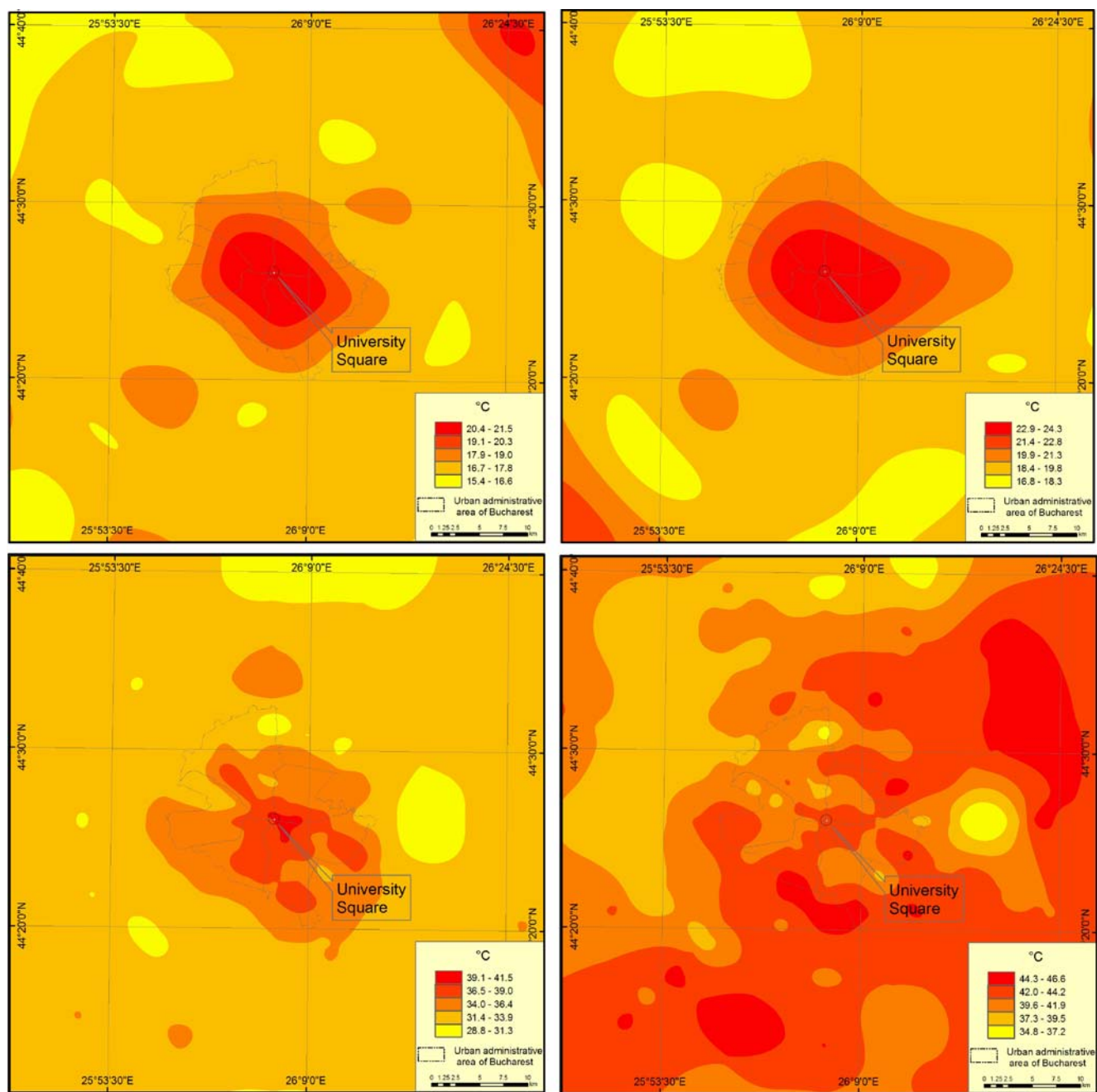


Fig. 15 Land-surface temperature around Bucharest as constructed from the MODIS products MOD11_L2 and MYD11_L2: nighttime 2000–2006 (above, left) and 2007 (above, right); day-time 2000–2006 (below, left), and 2007 (below, right)

Table 2 Shifting points (km) retrieved by the Rodionov test in the July LST (2000–2006) obtained from the MODIS products MOD_11L2 and MYD_11L2 over 16 geographic transects in Bucharest

Time	Exp	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Night	Exp1	7	6	6	7	10	8	7	9	8	7	7	7	7	8	7	7
	Exp2	6	6	5	7	6	8	7	8	8	6	7	7	7	8	7	7
Day	Exp1	9	9	9	7	7	11	7	5	9	7	8	9	7	7	9	8
	Exp2	9	9	9	5	7	11	7	12	12	7	8	9	7	7	9	8

The parameters of the two experiments are the following: a) *Exp1*: dataset filtered one time, $p=0.1$, cutoff = 10; b) *Exp2*: dataset filtered two times, $p=0.05$, cut-off = 5, 6, 7, 8, 9, 10 (aggregated)

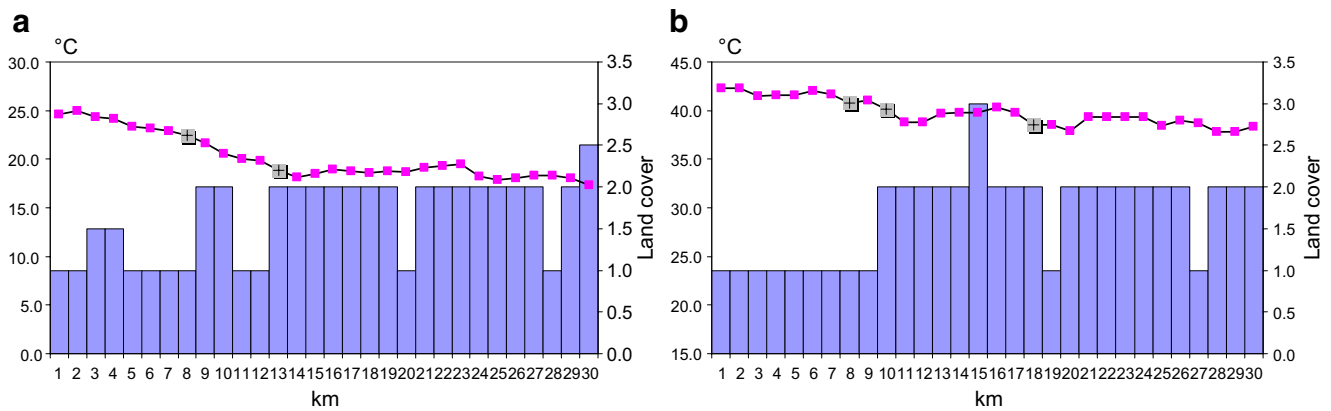


Fig. 16 The land cover¹Corine land cover database (2000); <<http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=667>> and the LSTs in July 2007: nighttime across the south (a) and day-time across the north-west transects (b). *Shadowed crosses* mark the shifting points returned by the Rodionov test. For the land cover, the

figures represent: 1.0 – Urban areas (i.e., continuous and discontinuous urban fabric, industrial and commercial units); 1.5 – Green urban areas; 2 – Arable land, pastures, complex cultivation patterns; 2.5 – Inland marshes; 3.0 – Water bodies

temporal gap between the satellite pass and the ground measurements.

The comparison between T_{air} measured at the Bucharest weather stations, and the LST of the corresponding pixels during the months of July 2000 to 2007 are presented in Table 3. For each available satellite image, the value of T_{air} might corresponds to a time gap of no more than 30 min, imposed by the available data. T_{air} and LST are generally well correlated, and the extreme high temperatures improved the correlations. The higher correlation coefficients remarked during the nighttime can be explained by the fact that it is the period when the Earth's surface behaves almost as an isothermal and homogeneous surface (Wang et al. 2008). The low spatial variation of both LST and T_{air} favor good correlations between the two parameters, more emphasized during extreme temperatures (Table 3). The very low score obtained by B-Filaret 2000–2007 for day-time could be the result of the specific heterogeneity in the area in comparison with the other two stations considered here.

Table 3 Correlation coefficients between T_{air} measured at the three weather stations in Bucharest and the LST of the corresponding pixels along the months of July 2000–2007

Time	B-Afumați	B-Filaret	B-Băneasa
Night 2000–2007*	0.87	0.83	0.81
Night 2007	0.94	0.91	0.89
Day 2000–2007*	0.72	0.51	0.70
Day 2007	0.79	0.74	0.85

*For B-Afumați, the available data are 2001–2007

6 Conclusions

The extremely high temperatures lasting over a long interval and covering a large area can substantially impact the behavior of an Urban Heat Island, both with respect to the air and, mostly, the skin temperature.

Regarding the T_{air} , its diurnal regime during the extremely hot July 2007 affecting the area of Bucharest was slightly modified, and the daily thermal difference between urban and extra urban weather stations amplified clearly just at dawn. The thermal amplitude between downtown and periphery is in a reversed relationship with the air temperature over the city, and the heat spell did not induce significant changes in this relationship.

Much more complex is the behavior of the land surface temperature. The nighttime Bucharest's UHI of July 2007 was intensified and extended in comparison to the multi-annual pattern, and the diurnal one was obliterated and dissipated. It is very likely that the persistence of an extremely hot air mass moderates dramatically the influence of the city on the daytime skin temperatures.

Since future investigations validate the high correlations we found between the T_{air} and LST, the results might be applied in more accurate evaluations of the UHI.

From the methodological point of view, studying the UHI based on satellite images, with a spatial resolution of 1 km, a temporal coverage of maximum four images per day and possibly extended over the whole metropolitan area of Bucharest as used here represents a significant progress compared with point data retrieved by two or three stations or with expeditionary cross-profiles. The MODIS products MOD11_L2 and MYD11_L2 have the potential to be exploited both in quasi-operational mode, as they usually are available within 24–72 h after the satellite overpass, and

in exploratory climatology studies, being available since 2000.

However, given the high complexity and heterogeneity of the factors that influence the generation and the parameters of the Bucharest UHI (i.e., urban fabric, land cover, atmospheric conditions), as well as its importance for numerous societal aspects, the monitoring and the studies should be envisaged at finer temporal and spatial scales too. Validation is also a part of our future work on the topic. Through combining information provided by satellite and aircraft remote sensing, weather stations and expeditionary experiments, one could expect further advancement.

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References

- Amfield AJ (2003) Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *Int J Climatol* 23:1–26
- Camilloni I, Barros V (1995) On the urban heat island effect dependence on temperature trends. *Clim Change* 37:665–681
- Cheval S, Dumitrescu A (2008) The July urban heat island of Bucharest as derived from MODIS images. *Theor Appl Climatol* doi:10.1007/s00704-008-0019-3
- Dash P, Göttsche F-M, Olesen F-S, Fischer H (2002) Land surface temperature and emissivity estimation from passive sensor data: theory and practice—current trends. *Int J Remote Sens* 23 (13):2563–2594
- Dousset B (1989) AVHRR-derived cloudiness and surface temperature patterns over the Los Angeles area and their relationship to land use. *Proc. IGARSS, Vancouver, Canada*, pp 2132–2137
- Dousset B, Gourmelon F, Mauri E (2007) Application of satellite Remote Sensing for Urban Risk Analysis: a case study of the 2003 extreme heat wave in Paris. *Urban Remote Sensing Joint Event, 2007*, 11–13 April, Paris. doi:10.1109/URS.2007.371849
- Gaffin SR, Rosenzweig C, Khanbilvardi R, Parshall L, Mahani S, Glickman H, Goldberg R, Blake R, Slosberg RB, Hillel D (2008) Variations in New York City's urban heat island strength over time and space. *Theor Appl Climatol*. doi:10.1007/s00704-007-0368-3
- Gallo KP, Tarpley JD, McNab AL, Karl TR (1995) Assessment of urban heat islands: a satellite perspective. *Atm Res* 37:37–43
- Hung T, Uchihama D, Ochi S, Yasuoka Y (2006) Assessment with satellite data of the urban heat island effects in Asian mega cities. *Int J Appl Earth Obs Geoinformation* 8(1):34–48
- Jin M, Shepherd JM (2005) Inclusion of urban landscape in a climate model. How can satellite data help? *Bull Am Meteorol Soc* 86 (5):681–689
- Jin M, Shepherd JM, Peters-Lidard C (2007) Development of a parameterization for simulating the urban temperature hazard using satellite observations in climate model. *Nat Hazards*. doi:10.1007/s11069-007-9117-2
- Mendelsohn R, Kurukulasuriya P, Basist A, Kogan F, Williams C (2007) Climate analysis with satellite versus weather station data. *Clim Change* 81:71–83
- Oke TR (1987) *Boundary layer climates*, 2nd edn. Methuen and Co. Ltd., London, p 435
- Pongrácz R, Bartholy J, Dezso J (2006) Remotely sensed thermal information applied to urban climate analysis. *Adv Space Res* 37:2191–2196
- Rao PK (1972) Remote sensing of urban “heat islands” from an environmental satellite. *Bull Am Meteorol Soc* 53:647–648
- Rodionov SN (2004) A sequential algorithm for testing climate regime shifts. *Geophys Res Lett* 31:L09204 doi:10.1029/2004GL019448
- Rodionov SN (2005) Detecting regime shifts in the mean and variance: methods and specific examples. In: Velikova V, Chipev N (eds) *Large-scale disturbances (regime shifts) and recovery in aquatic ecosystems: challenges for management toward sustainability*. UNESCO-ROSTE/BAS Workshop on Regime Shifts, Varna, Bulgaria, pp 68–72, 14–16 June 2005
- Scheuren J-M, le Polain de Waroux O, Below R, Guha-Sapir D, Ponsérre S (2008) *Annual disaster statistical review: the numbers and trends 2007*. CRED, Brussels, p 64
- Tumanov S, Stan-Sion A, Lupu A, Soci C, Oprea C (1999) Influences of the city of Bucharest on weather and climate parameters. *Atmos Environ* 33:4173–4183
- United Nations Human Settlements Programme (2007) *Enhancing urban safety and security: global report on Human Settlements 2007 (Part IV)*, p 448
- Wan Z, Zhang Y, Zhang Q, Li Z-L (2004) Quality assessment and validation of the MODIS global land surface temperature. *Int J Remote Sens* 25(1):261–274
- Wang W, Liang S, Meyers T (2008) Validating MODIS land surface temperature products using long-term nighttime ground measurements. *Remote Sens Environ* 112:623–635
- Weng Q, Larson RC (2005) Satellite remote sensing of Urban Heat Islands: current practice and prospects. In: Jensen RR, Gatrell JD (eds) *Geo-spatial technologies in urban environments*. Springer, Berlin Heidelberg New York, p 176