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COMPARISON OF THERMAL BEHAVIOUR OF DIFFERENT LAND COVER TYPES IN SLOVENIA AND CZECH REPUBLIC

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Abstract

This paper presents the results of a study of thermal behaviour of different land cover types in the Czech Republic and Slovenia. A hand-held thermal camera, Fluke Ti55, was used for data collection. Variation in the values of the surface temperature characteristics reflects the geographically dissimilar spaces. The investigation demonstrated impact of dense green vegetation and water bodies on the balanced thermal behaviour of landscapes in both countries. Thus, they appear to be cold spots with the lowest values. The most obvious variation in surface temperature is associated with artificial areas and bare surfaces. They usually represent hot spots in the landscape. In both countries similar thermal behaviour was found in artificial land cover types as opposed to agricultural land cover types.

Key words: hand-held thermal camera, land cover type, surface temperature, thermal behaviour, Czech Republic, Slovenia

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PRIMERJAVA TOPLOTNEGA ODZIVA RAZLIČNIH TIPOV POKROVNOSTI V SLOVENIJI IN NA ČEŠKEM

Izvleček

Prispevek predstavlja rezultate proučevanja toplotnega odziva različnih tipov pokrovnosti v Republiki Češki in Sloveniji. Podatki so pridobljeni s pomočjo prenosne termalne kamere "Fluke Ti 55". Velike razlike v temperaturi površja so posledica različnih geografskih razmer na Češkem in v Sloveniji. Raziskava je pokazala, da imajo v obeh državah gosto poraščene (gozd) in vodne (vlažne) površine uravnovešen toplotni odziv in v pokrajini običajno izstopajo kot hladne točke. Nasprotni temu so antropogeni tipi rabe tal in golo, neporaščeno površje, ki izkazujejo največjo temperaturno variabilnost in v pokrajini izstopajo kot vroče točke. V obeh državah je bil toplotni odziv antropogenih tipov rabe tal podoben, medtem ko se je najbolj razlikoval pri kmetijskih površinah.

Ključne besede: prenosna termalna kamera, tipi pokrovnosti, temperatura Zemljinega površja, toplotni odziv, Republika Češka, Slovenija

1 INTRODUCTION

In the recent years, satellite and aerial thermal infrared images have been extensively used in climatological studies of the landscapes due to the ease of access and relatively low costs. The use of small scale satellite and aerial thermal images is restricted to close-range (micro- and local scale) terrestrial studies into such phenomena as hot and cold spots, heat collection and loss, thermal behaviour in urbanized and artificial areas, including the urban heat island effect, local scale land cover changes, fractional vegetation cover, etc. The use of hand-held thermal camera enabled us to investigate the thermal behaviour of different active surfaces (i.e. the surface layer that is in contact with the atmosphere and which undergoes the greatest diurnal temperature changes, absorbing heat by day and radiating it to the atmosphere at night; Oxford Dictionary of weather, 2008; Vysoudil, 1993) respectively individual land cover types in high scale spatial resolution. One of the advantages of a hand-held camera is its flexibility in comparison with satellite/aerial monitoring.

The Fluke Ti55 Fusion is a thermal hand-held camera with recorded images in the spectral band from 8 µm to 14 µm. Image size (detector resolution) is 320x240 pixels, and field of view 23° horizontal by 17° vertical. Spatial resolution (pixel size) depends on the distance to target. The declared thermal sensitivity was ≤ 0.050 °C at 30 °C with accuracy ±2 °C or 2 %.

The landscape cover is composed of selectively radiating surfaces (bodies), such as rocks, soils, vegetation, water and artificial materials, all of which emit certain forms of energy. The output of energy, the emissivity, is selective and influenced by a number of factors, including albedo, surface texture, moisture content and the homogeneity of the active surface (Jensen, 2000). Natural materials have the capacity to conduct heat. Some materials respond to changes in temperature quicker than others.

The individual categories of land cover types were selected as representatives of typical (widespread) active surfaces. The USGS classification system of land use/land cover for using remote sensor data (Anderson et al., 1972) defines only level I and level II in reference to global/continental spatial resolution. Thermal images obtained by a hand-held camera recording *in situ* measurements made it possible to describe the thermal behaviour of the landscape on spatial level that applies to a local scale (region). Therefore we used Level IV CORINE Land Cover nomenclature (Bassard, Oťahel, Feranec, 2000) as individual areas of interest (AOI).

We expected variations in thermal behaviour due to local specifics such as types of vegetation (coniferous tree species, grass species, cultivated plant species), building materials, bedrock and local climate conditions. In section 2.4 we introduce 5 basic classes (level I) and their subclasses of level III that were thermally monitored. In the paper, categories of land cover types are in places only marked by numerical IDs. For example, 3.1.1, the broad-leaved forest land cover type, corresponds to category 3.1.1, etc.

When we used the hand-held thermal camera for topoclimate research for the first time (in 2008), we did not know how many years we would be able to continue our monitoring, or how many diverse localities we would investigate. This is why we obtained a lot of thermal image series from different geographical environments in different time periods. In 2009 we published our first results of surface thermal monitoring with a hand-held camera (Vysoudil, Ogrin, 2006). In the paper Středová, Středa, Vysoudil (2014), for example, we outlined some of the meaningful uses for this technique in geoscience research. One useful source of inspiration was the work of Kácovská (2017), who described a thermal picture of the landscape in the Natural Park Bystřice River Valley in Central Moravia (Czech Republic).

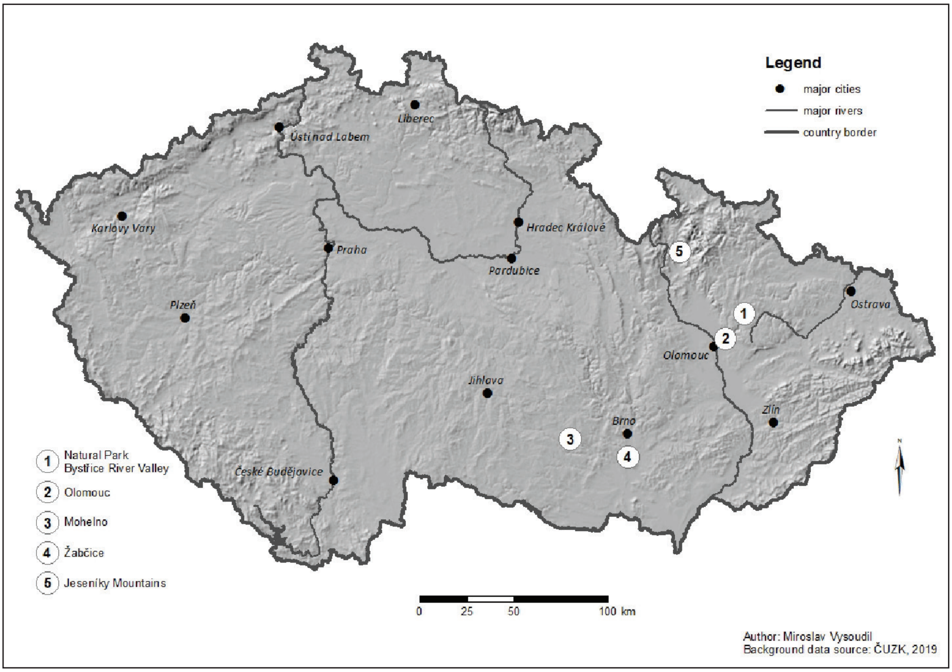
The results of our topoclimate research can be useful for urban planning and the development of smart cities, for vegetation and fauna species protection, for the management of the environment and more.

2 MATERIALS AND METHODS

2.1 Sites description

The investigation of the thermal behaviour of various land cover types was carried out in several areas of the Czech Republic (Moravia) (Figure 1): the city of Olomouc and its surroundings (2), Natural Park Bystřice River Valley (1), Natural Protected area Jeseníky Mountains (5), Natural protected area Mohelenská steppe (3) and an experimental agricultural field belonging to Mendel University of Brno in Žabčice (4).

Figure 1: Research areas in the Czech Republic.

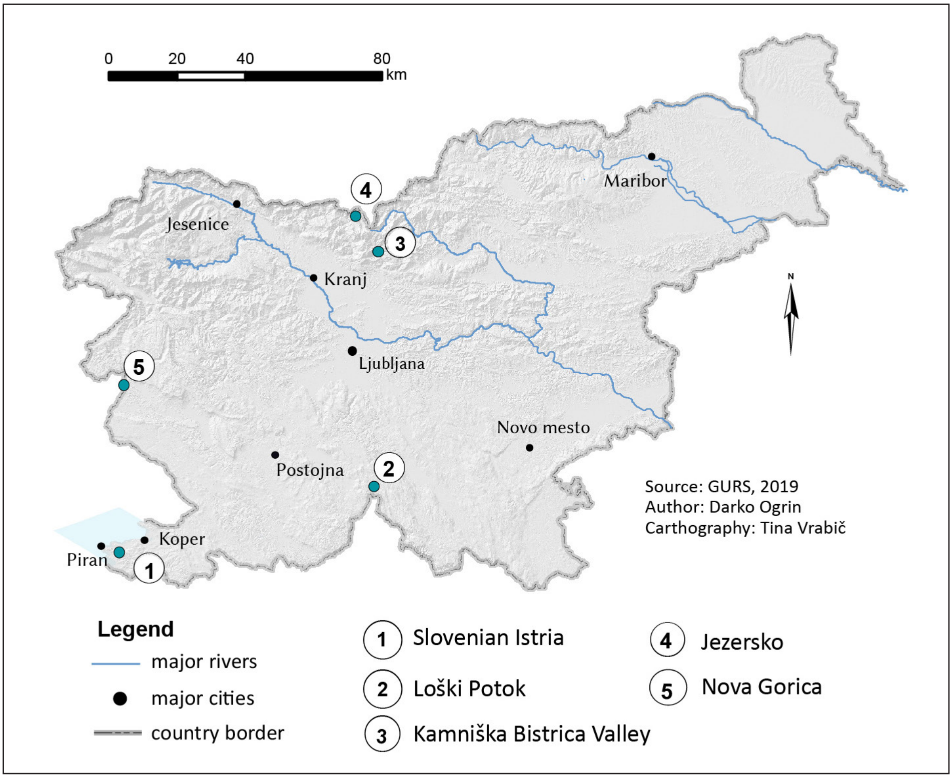


The areas of interest in Slovenia are in the sub-mediterranean part (the coast of the Istrian peninsula and the Nova Gorica region), the karst landscape in the southern part of Slovenia (the Loški Potok region) and two mountain areas in the Kamnik-Savinja Alps, namely the Kamniška Bistrica Valley and Jezersko with its environs (Figure 2).

The significant geodiversity and the high biodiversity of both regions led us to believe that we will acquire a thermal picture which will be representative of thermal behaviour in similar land cover types, albeit in geographically diverse areas.

In all cases the areas selected for thermal monitoring and the investigation of thermal behaviour were typical land cover types in the above mentioned regions, e.g. arable land including pastures, sparse vegetation, a range of forests, artificial areas, water bodies and bare surfaces. In thermal images selected land cover types at level III were delineated in detail, specifically their surface thermal behaviour. For example, bare surfaces, concrete, asphalt, pastures, water bodies, rocks, etc. were demarcated and separately analysed.

Figure 2: Research areas in Slovenia.



2.2 Time of research

The recordings of thermal images were mostly taken in the warm period of a year, i.e. in the growing season in both countries (April–September) between 2008 and 2018. The diurnal cycle of outgoing thermal radiation encompasses 24 hours (Jensen, 2000). Measurements were only set during the day time when the peak of long-wave radiation usually lags two to four hours behind the midday peak of incoming shortwave radiation (Jensen 2000). Because of the need to move from one selected location to another, measurements were taken in the hours before and after midday in order to ensure maximum irradiation. Daily time of measurements was set from late morning hours to early afternoon.

The weather conditions at the time thermal data is being recorded play a crucial role. Anderson and Wilson (1984) stated that wind speed should be <7 km/hr, fog should be minimal and cloud cover should also be minimal because clouds emit heat back to the active surface. These meteorological parameters were strictly adhered to on every occasion when readings were taken. The predominant radiative weather was characterized by cloudless skies (maximum 20 % cloud cover) and windless conditions (average wind speed up to 2 m/sec.). The only exception was data collection in the Loški potok area (2016) when typically advective weather affected monitoring. This allowed a comparison between the thermal behaviour of monitored land cover types in contrast to radiative weather during the data collection in 2017.

2.3 Camera calibration

The calibration of the thermal camera was carried out using a method adapted from Wurm's (2007) work. We measured water temperature with calibrated digital and/or liquid-in-glass thermometers, and surface temperatures were recorded by the thermal camera.

Table 1: Water emissivity (Ɛ), water surface temperature (Tw,cam; °C) and temperature of standing water (Tw; °C) in the depths 0.05 m and 0.10 m (own measurements).

Test №	**Tw (°C)**		**Water emissivity (Ɛ)**		**Tw,cam (°C)**	**Camera error (Tw-Tw,cam; °C)**	
	0.05 m	**0.10 m**	**pyrometer**	**camera**		**0.05 m**	**0.10 m**
1	6.1	6.1	0.64	0.64	4.0	**2.1**	**2.1**
2	6.2	6.1	0.65	0.65	4.1	**2.1**	2.0
3	6.1	6.0	0.64	0.64	3.9	2.2	**2.1**

Table 2: Water emissivity (Ɛ), water surface temperature (Tw,cam; °C) and temperature of stream water (Tw; °C) at depths 0.05 m and 0.10 m (own measurements).

Test №	**Tw (°C)**		**Water emissivity (Ɛ)**		**Tw,cam (°C)**	**Camera errors (Tw-Tw,cam; °C)**	
	0.05 m	**0.10 m**	**pyrometer**	**camera**		**0.05 m**	**0.10 m**
1	1.9	1.9	0.64	0.64	-0.2	**2.1**	**2.1**
2	2.0	1.9	0.64	0.64	-0.1	**2.1**	2.0
3	2.0	1.9	0.64	0.64	-0.1	**2.1**	2.0

The values displayed on the thermal camera used for the experiments showed an average surface temperature 2.1 °C lower than the true values measured by the calibrated digital and/or liquid-in-glass thermometers. However, for our purpose relative temperature values were sufficient.

2.4 Land cover types

The land cover types that were examined during the study, using CORINE Land Cover nomenclature (Bossard, Oťahel, Feranec, 2000), are listed below. Their potential influences on thermal behaviour are also shown.

1 Artificial areas: 1.1 urban fabric (1.1.1 continuous urban fabric, 1.1.2 discontinuous urban fabric, 1.1.3 industrial or commercial units, 1.1.4. road and rail networks and associated land, 1.1.7 green urban areas).

Artificial areas are composed of various materials, thus it is necessary to take into consideration parameters such as building material and building density, transportation network, etc. The commercial and industrial types of land cover constituted by nonporous materials have the highest surface temperatures during the day. The most common heterogeneous land cover, such as buildings and spaces of urban green vegetation showed an intermediate surface temperature.

2 Agricultural areas: 2.1 arable land (2.1.1 non-irrigated arable land, 2.1.2 vineyards, 2.1.3 fruit trees and berry plantations, 2.1.5 pastures, 2.1.6 annual crops associated with permanent crops).

The thermal behaviour of agricultural areas is determined primarily by the physical state of the vegetation; its health condition, vegetation phase resp. the season of the year, and the diversity of species. These factors must be considered when describing the thermal behaviour of agricultural areas.

3 Forest and Semi-natural Areas: 3.1 forests (3.1.1 broad-leaved forest, 3.1.2 coniferous forest, 3.1.3 mixed forest, 3.1.4 natural grassland, 3.1.6 bare rock, 3.1.7 sparsely vegetated areas).

The thermal behaviour of the forest and semi-natural areas depends on vegetation species diversity and density, resp. bare surface rate. The age of vegetation and its health condition are considerably affected by the season of the year.

4 Wetlands: (4.1.1 salines).

The wetlands occur sporadically as land cover type in both countries and were represented only by salines in the coastal part of Slovenia. They usually have the nature of homogeneous surfaces with uniform thermal field colder in comparison with forests and semi-natural areas.

5 Water bodies: 5.1 water bodies (5.1.1 water courses, 5.1.2 water bodies, 5.1.3 sea and ocean).

Water bodies are considered highly homogeneous surfaces, their more or less uniform thermal behaviour mostly reflects the physical properties of water, including depth and state (level) of motion. The thermal behaviour of water bodies varies when comparing small ponds and brooks with large lakes or open sea surfaces. The large lakes and open sea surfaces look as colder spaces in the landscape.

2.5 Data processing

The images were processed and analysed using Fluke SmartView® software when the first visible and thermal images were spatially rectified. The next steps included thermal scale adaptation, and the possible correction of emissivity values of selected cover types that were defined and researched on individual thermal images by Sobrino et al. (2012; see also Fluke, 2007).

In order to obtain realistic picture of the nature of the thermal fields we used Fluke SmartView® software's automatically generated variables:

- average surface temperature (Tavg),
- standard deviation of surface temperature (s) as a value that shows the variation of surface temperature.

Additionally we calculated:

- amplitude of surface temperature (Ta),
- variation coefficient (c), which was used to compare variation between selected areas (surfaces) that showed different averages.

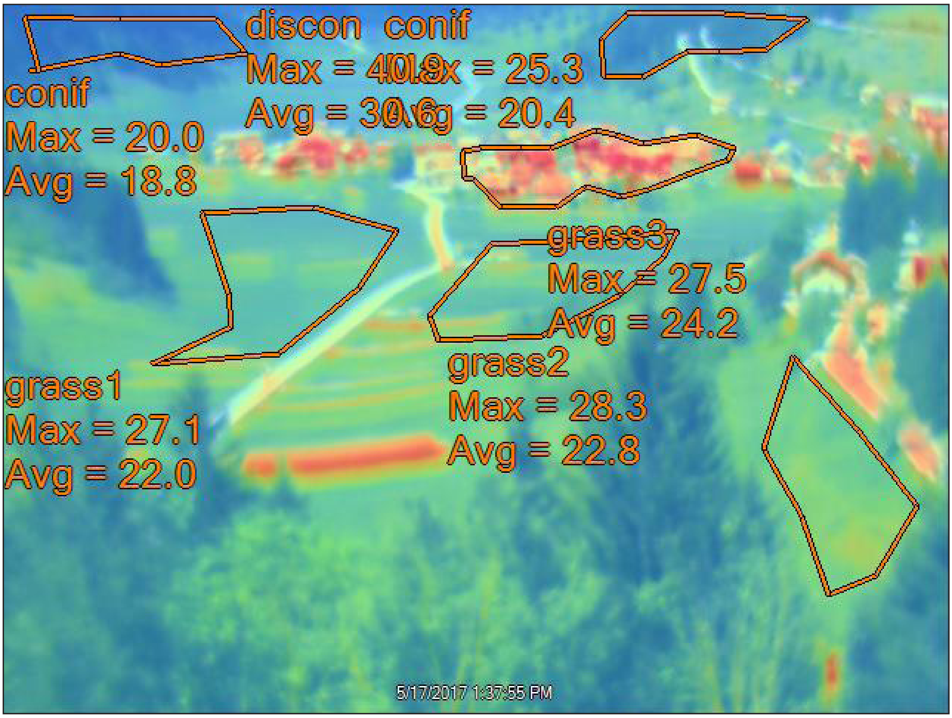
Surface temperature characteristics reflect the thermal behaviour of selected land cover types due to their physical properties and their homogeneity/inhomogeneity. In practice, after acceptable thermal image selection (Figure 3), for individual selected areas of interest (AOI) that belonged to one of the observed land cover types (see above CORINE land cover classes) we calculated the above mentioned statistics for the subsequent analyses.

Table 3: Basic surface temperature characteristics (°C) of selected land cover types (LCT) from Figure 3.

LCT	Tavg	s	Ta	c
3.1.4 natural grassland	18.5	1.1	6.8	6.1
3.1.4 natural grassland	18.6	0.7	4.9	3.9
3.1.4 natural grassland	18.1	0.9	7.3	4.9
3.1.2 coniferous forest	16.9	0.5	2.6	2.7
3.1.2 coniferous forest	21.7	1.2	5.7	5.4
1.1.2 discontinuous urban fabric	26.3	4.3	19.9	16.2

Tavg: average surface temperature
s: standard deviation of surface temperature
Ta: amplitude of surface temperature
c: variation coefficient

Figure 3: Selected land cover types and their surface temperature characteristics automatically generated by Fluke SmartView® software (the Retje Polje, SI).



In the next step, values of surface temperature characteristics of all selected (investigated) land cover types (LCT) were summarized in tables, which were used for evaluation of thermal behaviour of LCT in the investigated localities in both countries. Description and comparison of thermal behaviour of the individual land cover types and their possible dissimilarities were based on interpretation of statistical characteristics with emphasis on average temperature, temperature amplitude, standard deviation and variation coefficient. We suppose that regional differences in thermal behaviour of land cover types between Czech and Slovenian research areas are primarily the result of specific geo- and biodiversity characteristics, bedrocks, different artificial materials, etc.

3 RESULTS

3.1 Evaluation of surface temperature characteristics of land cover types' thermal behaviour

In accordance with the main goals of the study we analysed surface temperature characteristics of selected land cover types (and simultaneously described their thermal behaviour) and the differences between locations in the Czech Republic (CZ from now on) and in Slovenia (SI from now on). In the first part of this section detailed description of investigation for one representative locality in Czech Republic and one in Slovenia is presented. For understanding the thermal behaviour of the land cover types comparison of temperature amplitude, standard deviation and coefficient of variability that reflect level of homogeneity of investigated LCT is of crucial importance. At the same time, it allows comparison of thermal behaviour between individual land cover types. The second part presents general results of the research on thermal behaviour of all LCTs in investigated areas of interest in the Czech Republic and in Slovenia and their comparison.

3.1.1 Case Study Natural Park Bystřice river Valley (CZ)

The detailed analysis of surface temperature and thermal behaviour of 11 land cover types on level III (namely discontinuous urban fabric 1.1.2, non-irrigated arable land 2.1.1, pastures 2.1.5, annual crops 2.1.6, broad-leaved forest 3.1.1, coniferous forest 3.1.2, mixed forest 3.1.3, natural grassland 3.1.4, bare surfaces 3.1.6, sparse vegetation 3.1.7, water bodies 5.1.2) and in 45 AOIs was performed for selected research areas in the Natural Park Bystřice River Valley (Central Moravia). Characteristics presented in Tables 4 and 5 are summary values of all campaigns that were carried out in the area in the period 2015–2017.

Table 4: Thermal characteristics (°C) of basic monitored land cover types (LCT) in the Natural Park Bystřice River Valley (CZ).

LCT	Tavg	s	Ta	c
1.1.2	24.4	3.4	19.4	14.0
2.1.1	15.5	1.2	5.6	7.5
2.1.5	17.6	0.6	3.6	3.5
2.1.6	20.1	0.3	1.3	1.4
3.1.1	15.2	0.7	4.4	4.9
3.1.2	18.2	0.8	5.8	4.6
3.1.3	18.7	1.1	6.5	5.6
3.1.4	18.5	0.8	4.7	4.2
3.1.6	25.0	1.4	7.9	5.5
3.1.7	20.7	1.5	8.1	7.1
5.1.2	11.3	1.1	4.8	9.4

Tavg: average surface temperature
s: standard deviation of surface temperature
Ta: amplitude of surface temperature
c: variation coefficient

Table 5: The comparison of average surface temperature (Tavg, °C), surface temperature amplitude (Ta, °C), standard deviation (s, °C), and variation coefficient (c) in descending order of basic monitored land cover types (LCT) in the Natural Park Bystřice River Valley.

Characteristic	Descent order
Tavg	3.1.6 >1.1.2 >3.1.7 >2.1.6 >3.1.3> 3.1.4 >3.1.2> 2.1.5 >2.1.1 >3.1.1 >5.1.2
Ta	1.1.2> 3.1.7 >3.1.6 >3.1.3 >3.1.2> 2.1.1> 5.1.2> 3.1.4> 3.1.1 >2.1.5 >2.1.6
s	1.1.2 >3.1.7 >3.1.6 >2.1.1 >3.1.3> 5.1.2 >3.1.2> 3.1.4 >3.1.1> 2.1.5> 2.1.6
c	1.1.2 >3.1.7 >3.1.6 >3.1.2 >2.1.1 > 3.1.3 >5.1.2 >3.1.4 >3.1.1 > 2.1.5 >2.1.6

Tavg: average surface temperature
Ta: amplitude of surface temperature
s: standard deviation of surface temperature
c: variation coefficient

Figure 4: Thermal field of southern part of Natural Park Bystřice River Valley (CZ).

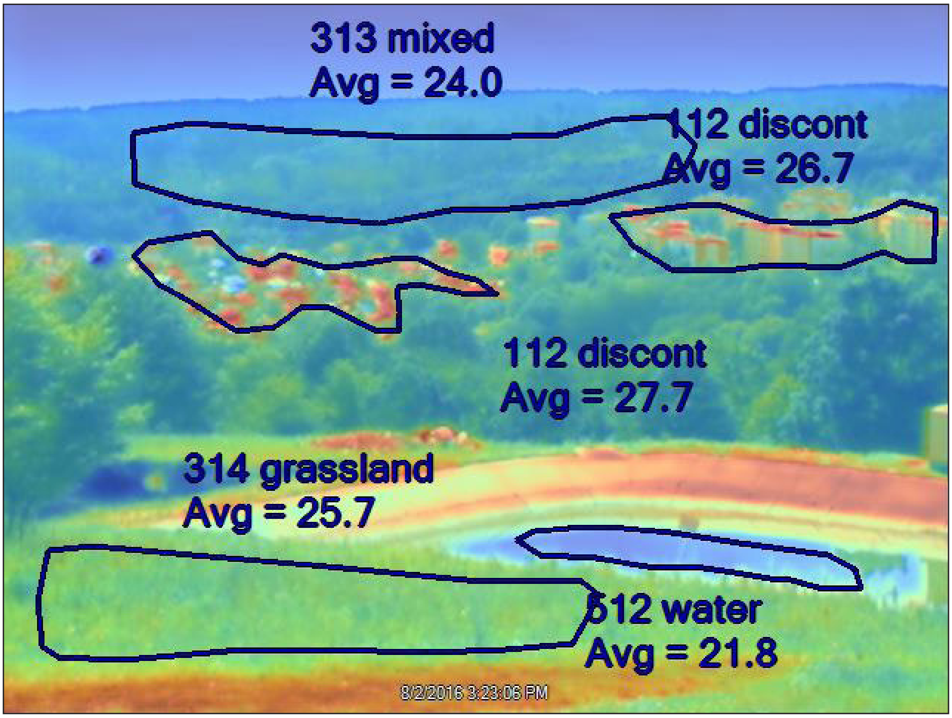
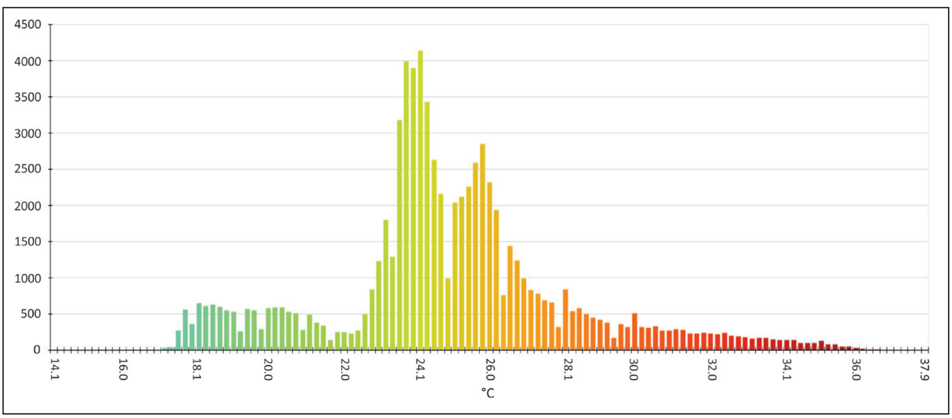


Figure 5: Histogram of surface temperature pixels for the area on Figure 4.



The most balanced regime of surface temperature with low amplitude can be found in localities with dense vegetation or forested areas. The similar results were found also for water bodies. The above-mentioned surfaces show high level of homogeneity. By contrast, the highest amplitudes of surface temperatures are observed in urbanized areas, localities with sparse vegetation or bare surfaces.

The analysis shows impact of vegetation cover on balanced temperature regime of landscape. The forests, grassland, pastures, arable land and water bodies mostly look like coldest places (Figure 4, 5). On the other hand, areas of interest, such as anthropogenic surfaces, bare surfaces and surface without green vegetation or with low ratio of vegetation, represent hot spaces in landscape.

3.1.2 Case study Loški Potok (Slovenia)

In Slovenia, the Loški Potok region (namely the village of Retje and Retje Polje, Figure 3) was selected as a case study due to specific local geographical conditions (karst relief and its underlying rocks). Prevailing land cover types in the area of interest were discontinuous urban fabric (1.1.2), natural grasslands (3.1.4) and coniferous forests (3.1.3).

The investigations were carried out in September 2016 and May 2017. Meteorological conditions during experiments (predominantly radiative weather in 2017, advective weather in 2016) draw attention to a decisive role which is played by weather types in thermal behaviour of landscape cover. Additionally, in 2017 the investigation of thermal behaviour of selected land cover types took place both in the day time and in the night time.

Radiative weather (day time – night time)

The nature of day time thermal behaviour of some land cover types in comparison with the night time regime was studied in the Loški Potok area. The Tables 6 and 7 and Figure 6 demonstrate thermal variability between day-, and night time.

Thermal behaviour of selected land cover types in day time during maximum insolation reflects variations related to physical matter of surfaces and buildings material. The extreme standard deviation and temperature amplitude of urbanised areas with mostly inhomogeneous man-made surfaces indicate distinct thermal variability, in contrast to the vegetation.

In the night time when surface radiative balance is negative, nature of thermal field is also dramatically changed. Even if it is not uniform, the differences between individual surfaces become smaller. The urbanised areas remain the hottest, but level of cooling in comparison with green vegetation is highly evident. The vegetation cover that plays the role of colder environment during day stays relatively warmer in the night.

Table 6: Thermal characteristics (°C) of monitored land cover types in the Loški potok region (SI), radiative weather, day time vs. night time (D-N).

LCT	Tavg			s			Ta			c		
	day	night	D-N	day	night	D-N	day	night	D-N	day	night	D-N
1.1.2	27.9	11.6	16.3	3.9	1.1	2.8	19.3	5.6	13.7	14.0	9.3	4.7
3.1.4	19.4	7.6	11.8	1.0	0.4	0.6	5.9	2.7	3.2	5.0	5.6	-0.6
3.1.2	19.0	11.8	7.2	0.7	0.5	0.2	3.8	3.0	0.8	3.4	4.4	-1.0

Tavg: average surface temperature
s: standard deviation of surface temperature
Ta: amplitude of surface temperature
c: variation coefficient

Table 7: The comparison of average surface temperature (Tavg, °C), surface temperature amplitude (Ta, °C), standard deviation (s, °C), and variation coefficient (c) in descending order of basic monitored land cover types in the Loški potok region (SI), radiative weather, day time vs. night time.

Characteristic	Descending order, day time	Descending order, night time
Tavg	1.1.2 > 3.1.4 > 3.1.2	3.1.2 > 1.1.2 > 3.1.4
Ta	1.1.2 > 3.1.4 > 3.1.2	1.1.2 > 3.1.2 > 3.1.4
s	1.1.2 > 3.1.4 > 3.1.2	1.1.2 > 3.1.2 > 3.1.4
c	1.1.2 > 3.1.4 > 3.1.2	1.1.2 > 3.1.4 > 3.1.2

Tavg: average surface temperature
s: standard deviation of surface temperature
Ta: amplitude of surface temperature
c: variation coefficient

Figure 6: Differences day- vs. night-time of average surface temperature (Tavg), surface temperature amplitude (Ta) and standard deviation (s) of monitored land cover types (LCT) in the Loški Potok region (SI), radiative weather.

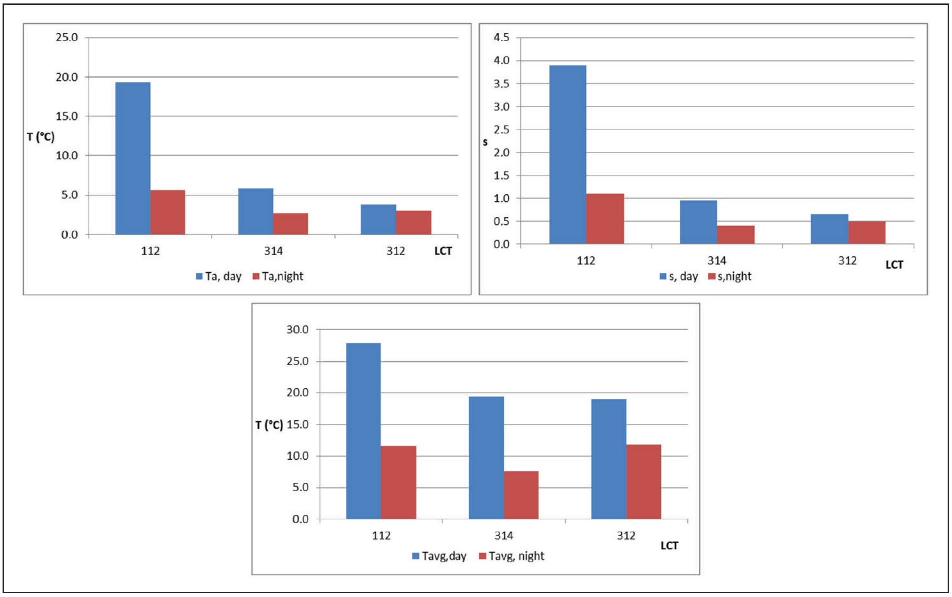
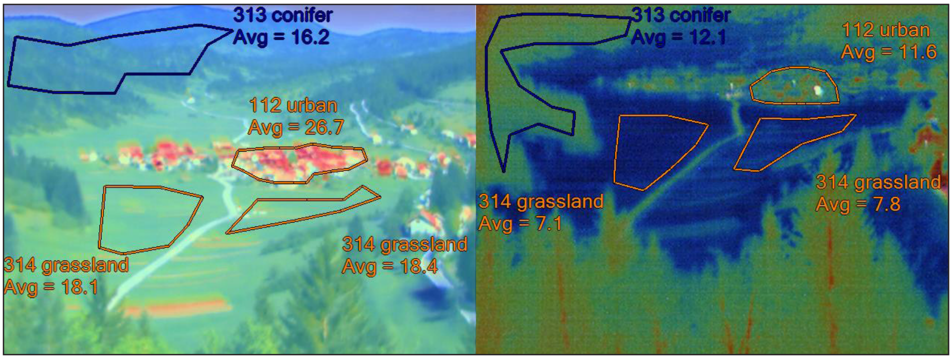


Figure 7: Thermal images of Retje Polje (Loški Potok region, SI) in day-time (left) and night-time (right).



Radiative vs. advective weather

The results of thermal monitoring (Table 8, Figure 8) demonstrate clearly the role of advective weather that restricts microclimate shaping.

Table 8: Thermal characteristics (°C) of monitored land cover types in the Loški potok region (SI), radiative (Rw) vs. advective weather (Aw).

LCT	Tavg			s			Ta			c		
	Rw	Aw	Rw-Aw	Rw	Aw	Rw-Aw	Rw	Aw	Rw-Aw	Rw	Aw	Rw-Aw
1.1.2	27.9	16.0	11.9	3.9	0.2	3.7	19.3	1.6	17.7	14.0	1.3	12.7
3.1.4	19.4	19.1	0.3	1.0	1.0	0.0	5.9	4.9	1.0	5.0	5.2	-0.2
3.1.2	19.0	15.0	4.0	0.7	0.2	0.5	3.8	0.8	3.0	3.4	1.3	2.1

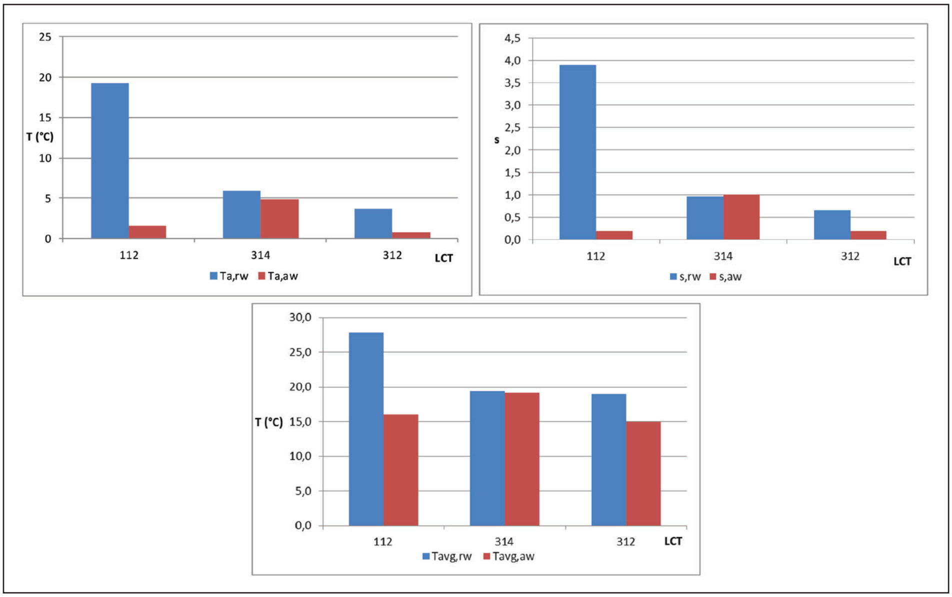
Tavg: average surface temperature
s: standard deviation of surface temperature
Ta: amplitude of surface temperature
c: variation coefficient

Table 9: The comparison of average surface temperature (Tavg, °C), surface temperature amplitude (Ta, °C), standard deviation (s, °C), and variation coefficient (c) in descending order of basic monitored land cover types (LCT) in the Loški potok region (SI), advective vs. radiative weather.

Characteristic	Descending order, advective weather	Descending order, radiative weather
Tavg	3.1.4 > 1.1.2 > 3.1.2	1.1.2 > 3.1.4 > 3.1.2
Ta	3.1.4 > 1.1.2 > 3.1.2	1.1.2 > 3.1.4 > 3.1.2
s	3.1.4 >1.1.2 ~ 3.1.2	1.1.2 > 3.1.4 > 3.1.2
c	3.1.4 >1.1.2 ~ 3.1.2	1.1.2 > 3.1.4 > 3.1.2

Tavg: average surface temperature
Ta: amplitude of surface temperature
s: standard deviation of surface temperature
c: variation coefficient

Figure 8: Differences of average surface temperature (Tavg), surface temperature amplitude (Ta) and standard deviation (s) of monitored land cover types (LCT) in the Loški potok region (SI), radiative vs. advective weather.



Thermal behaviour of individually investigated surfaces as well as of the whole area in the day with advective weather is in fact uniform, thermal field appears highly homogeneous (Table 8, Figure 8). Discontinuous urban fabric as the most thermally non-homogenous land cover type is not dominant in thermal picture of the area. Relatively higher dissimilarities in the case of natural grasslands cover probably reflect seasonal (autumn) changes of green vegetation. The descending order of thermal characteristics of LCT (Table 9) show main changes in thermal behaviour. In the case of advective weather natural grasslands show the most variable thermal behaviour. In the case of radiative weather discontinuous urban surfaces were thermally most variable. The most stable thermal fields in both weather types belong to coniferous forest.

3.2 Comparative analysis of thermal behaviour of land cover types

The comparative analysis of thermal behaviour of monitored areas of interest was carried out for 4 basic land cover types (level I) and corresponding subtypes (level III), separately for AOIs in the Czech republic and in Slovenia with a goal to evaluate discovered anomalies. The description arises from the values that reflect level of variability; we used surface temperature amplitude (Ta), standard deviation (s) and coefficient of variability (c). In the cases of distinctive dissimilarities, the specification of the most probable causes was crucial regarding the primary goals of investigation.

Table 10: The average surface thermal characteristics (°C) of selected land cover types (level I) in Slovenia (SI) and in the Czech Republic (CZ).

Characteristic	Artificial LCT		Agricultural LCT		Forested, Semi-natural LCT		Water bodies LCT	
	SI	CZ	SI	CZ	SI	CZ	SI	CZ
Ta	12.6	22.3	7.3	18.7	7.2	5.9	4.2	5.8
s	2.7	3.8	1.7	3.4	1.3	0.6	0.7	1.2
c	10.2	12.0	4.7	3.7	5.7	5.2	14.0	7.8

Ta: amplitude of surface temperature
s: standard deviation of surface temperature
c: variation coefficient

Artificial areas

Thermal field of artificial areas is distinctive and its nature depends on type of land cover when man-made surfaces are dominant (Figure 9).

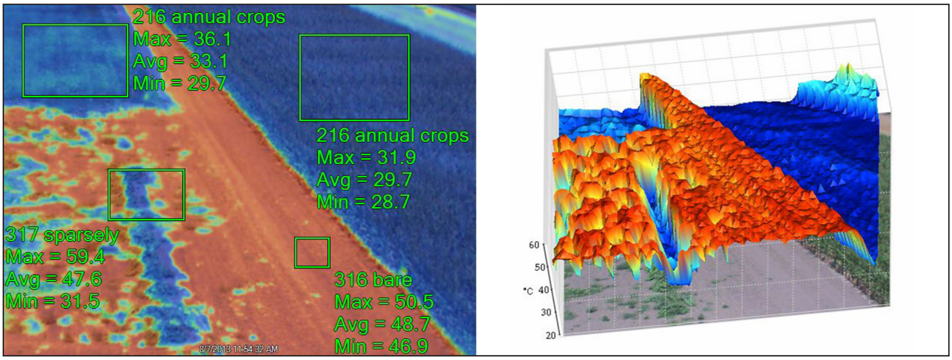
Summary surface thermal characteristics of artificial areas in SI and CZ (Table 10) appear similar in all respects. When comparing characteristics at level III, it is evident that artificial land cover types show very dynamic thermal behaviour.

Figure 9: Thermal field of artificial areas LCTs in Nova Gorica (urban fabric; left, SI) compared to Jezersko (village fabric; right, SI).

Agricultural areas

Thermal characteristics of agricultural areas in both countries and their dissimilarities can be caused by different systems of agricultural production (e.g. differences in farm size structure), and also different structure of cultivated species (Figure 10).

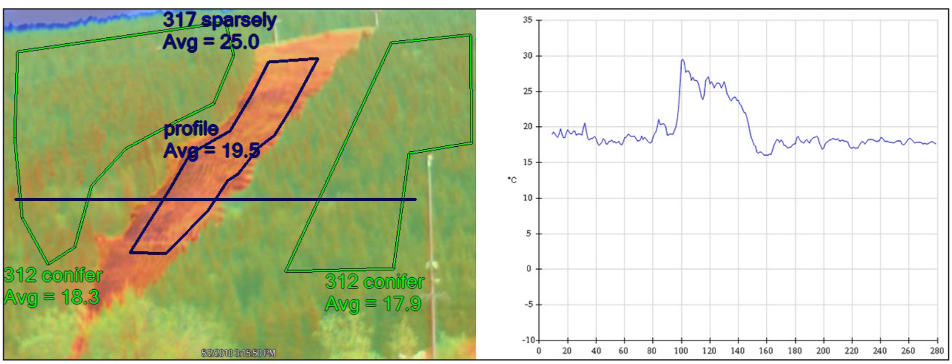
Figure 10: Thermal field of agricultural LCT in comparison with bare LCT, Žabčice (CZ), right 3D graph.



Forests and Semi-natural areas

Variation characteristics of forested and semi-natural land cover types in the CZ show lower values (Table 10). This means that vegetation is more homogeneous and dense. This speculation is also supported by surface temperature amplitude value. Similar situation was shown also by the results of monitoring of individual subclasses on level III.

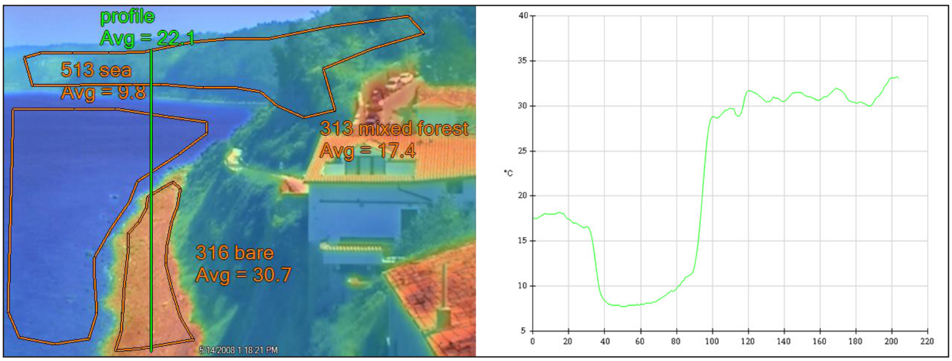
Figure 11: Thermal field of forest and semi-natural area LCT (right thermal surface profile), Jeseníky Mountains (CZ).



Water bodies

It was expected that basic observed thermal characteristics (Tavg, Tmax, Tmin) of land cover types will vary due to geographical conditions (e.g. latitude) and type of substance (sea water in SI, inland water in CZ). On the other hand similar overall mass properties of water reflect very similar variation parameters, e.g. standard deviation (s) and coefficient of variability (c).

Figure 12: Thermal field of sea water in comparison with bare rock and forest LCT (right thermal surface profile), Piran peninsula (SI).



4 DISCUSSION

Discussion of dissimilarities of thermal behaviour of basic land cover types between both countries is based on statistic characteristics, which allow comparison (see Chapter 2). The wetlands were not taken into account due to the fact that only one area in Slovenia was monitored. Numerical ID represents these basic land cover types of level I: 1 artificial areas, 2 agricultural areas, 3 forests and semi-natural areas, and 5 water bodies. Table 11 presents comparison of monitored LCT according to statistical characteristics in their descending order.

Table 11: Comparison of thermal characteristics of LCT (level I) between CZ and SI in descending order.

Characteristic/Country	Descending order
Average temperature	
CZ	1 > 3 > 2 > 5
SI	1 > 2 > 3> 5
Temperature amplitude	
CZ	1 > 3 > 5 > 2
SI	1 > 2 > 3 > 5
Standard deviation	
CZ	1 > 3 > 5 > 2
SI	1 > 2 > 3 > 5
Coefficient of variability	
CZ	1 > 5 > 3 > 2
SI	1 > 5 > 3 >2

Artificial areas
When comparing average surface temperatures the values that belong to the artificial areas (1) were the highest in all cases in CZ as well as in SI. They are hot spots in landscape; on the other hand the highest values of standard deviation and coefficient of variability reflect their thermal inhomogeneity. The high thermal amplitude reflects specific thermal properties (heat capacity, thermal conduction, heat emission etc.). Different geographical conditions in the case of artificial (man-made) surfaces do not play a role.

Agricultural areas
Average surface temperature, temperature amplitude and standard deviation of agricultural areas were in Slovenia second highest, but higher than in the Czech Republic. Coefficient of variation of agricultural areas shows the absolutely lowest values of all researched land cover types in both of the countries. Differences between thermal behaviour of agricultural, forest and semi-natural areas in both countries reflect differences in their structure, e.g. vegetation species.

Forest and semi-natural areas
The coefficient of variation of forest and semi-natural areas (3) is the second lowest, both for the Czech Republic and Slovenia. Other statistical characteristics show higher levels in the areas in the Czech Republic than in Slovenia The reasons could be in

the higher level of homogeneity of forested areas in Slovenia, and on the other hand in probably higher diversity of tree species in the Czech Republic.

Water bodies

Thermal behaviour of water bodies (5) reflects well physical (thermal) properties of water. In both areas of investigation water bodies have the lowest average temperatures, low values of standard deviation, and high values of coefficient of variation. If we compare the results for the Czech Republic and Slovenia, water bodies in Slovenia (sea surfaces) showed more homogeneous thermal field and thermal behaviour. Higher turbidity of water streams in the Czech Republic is probably the cause of these differences. It is evident that water bodies play important role as cooler islands in the landscape. It appears that for description of thermal behaviour of water bodies inland waters and sea water should be compared separately.

5 CONCLUSIONS

The knowledge about thermal behaviour of landscape is crucial when climate in small areas (local climate) is studied. The related research is especially complicated in the cultural landscape in geographical areas with high level of geo- and biodiversity such as our research areas in the Czech Republic and Slovenia. It involves taking into account strict requirements on thermal data gathering methods, particularly in regard to the spatial resolution of thermal images. Our results show that for surfaces that spatially correspond to the land cover types level III, respectively level IV, surface thermal monitoring provide the best sort of data with spatial resolution below 1 meter, if necessary. These images are fit for local analyses of thermal behaviour variability and local climate studies. This can be considered the biggest advantage of surface measurement unlike satellite monitoring.

In order to obtain relevant knowledge on thermal picture of landscapes in different geographical spaces, systematic spatial investigation would be needed. It should take into consideration daytime, season of a year and weather situations.

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PRIMERJAVA TOPLOTNEGA ODZIVA RAZLIČNIH TIPOV POKROVNOSTI V SLOVENIJI IN NA ČEŠKEM

Povzetek

Primerjalna raziskava toplotnega odziva značilnih tipov pokrovnosti je potekala na več lokacijah na Moravskem (vzhodna Češka) in v Sloveniji. V raziskavo so bile vključene antropogene površine, obdelovalne površine, gozdne površine in površine z ostalo naravno vegetacijo, mokrišča in vodne površine. Tipe pokrovnosti smo izbrali glede na “CORINE Land Cover”. Snemanje površja s termalno kamero “Fluke Ti55” je potekalo v obeh državah v topli polovici leta v obdobju 2008–2018, praviloma ob jasnem in mirnem vremenu na višku dneva, ko je sevanje površja največje. Le v primeru posebnih primerjav smo snemanje opravili tudi ob advekcijskem tipu vremena in ponoči. Termalne posnetke površja smo obdelali in analizirali s programsko opremo “Fluke SmartView®”. Glavne značilnosti toplotnega okolja posameznih tipov pokrovnosti smo ugotavljali s pomočjo povprečne temperature površja, standardnega

odklona temperature površja, amplitude temperature površja in koeficienta variacije. Uporabljali smo relativne vrednosti temperature površja, ki so v povprečju za 2,1 °C nižje od dejanskih vrednosti, ki smo jih odčitali s pomočjo umerjenih termometrov.

V prvem delu raziskave smo analizirali toplotni odziv dveh reprezentativnih lokacij, v Naravnem parku doline Bistrice na Češkem in Loškem potoku v Sloveniji, v drugem delu je raziskava dopolnjena še z dodatnimi primeri iz obeh držav. Antropogene površine izkazujejo najvišje vrednosti temperature površja v raziskanih primerih obeh držav. V pokrajini predstavljajo vroče točke, ki pa imajo precej nehomogene temperaturne razmere, kar je razvidno iz najvišjih vrednosti standardnega odklona in koeficienta variabilnosti. To je posledica razlik v pozidavi in pestrosti rabe tal znotraj teh površin. Statistični pokazatelji za kmetijske površine kažejo na večje razlike v toplotnem odzivu med obema državama, kakor tudi med primeri znotraj posamezne države, kar je posledica različnih kulturnih rastlin in specifike njihovega pridelovanja. Značilno je, da je temperaturni odziv posameznih kmetijskih površin zelo homogen. Na splošno je analiza izpostavila višje vrednosti povprečne temperature površja kmetijskih površin in temperaturne amplitude ter standardnega odklona za slovenske primere. Podobne značilnosti kot za kmetijske površine veljajo tudi za gozd, kjer pridejo do izraza razlike v vrstni sestavi gozda, pokrovnost ipd. Tudi za posamezne primere gozdne rabe velja, da so njihova temperaturna polja zelo homogena v obeh državah. Toplotni odziv vodnih površin zelo dobro odraža fizikalne lastnosti vode. Na konkretnih primerih to pomeni najnižjo povprečno temperaturo, nizke vrednosti standardnega odklona, vendar višje vrednosti koeficienta variacije, ki gredo na račun razlik v obravnavanih vodnih telesih v obeh državah. Proučene vodne površine v Sloveniji, predvsem na račun morja, imajo večjo homogenost temperaturnega polja v primerjavi s Češko, kjer smo proučili le površinsko tekoče vode. Iz vseh analiziranih primerov pa izhaja, da predstavljajo vodne površine hladne točke v pokrajini v obeh državah.

Poznavanje toplotnega odziva v pokrajini je pomembno pri raziskovanju lokalnega in mikro podnebja. Poseben izziv predstavlja to raziskovanje v kulturni pokrajini in pokrajinah z visoko stopnjo geo- in biodiverzitete, kjer nastopajo številni tipi in podtipi pokrovnosti, ki se prostorsko zelo spreminjajo. Iz tega izhaja velika pestrost toplotnih okolij in posledično tudi temperature zraka pri površju. V takih primerih je snemanje površja s termalno kamero zelo dober pripomoček za analizo lokalnega in mikro podnebja, saj je lahko prostorska ločljivost podatkov tudi manjša od 1 m.