An estimation of the accuracy of the topoclimate range based on the land surface temperature with reference to a case study of the Drawa National Park, Poland

Marek Półrolniczak¹ · Aleksandra Zwolska¹ · Leszek Kolendowicz¹

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Abstract

Topoclimate depends on specifically local-scale climatic features caused by the interrelations between topography, water, soil, and land cover. The main purpose of this study is to identify, characterize, and delimit the range of topoclimate types at the Drawa National Park (DPN) and to estimate their accuracy while taking into consideration the thermal conditions of the land surface. Based on a set of digital maps, and with the use of the heat-balance Paszyński method, seven types of topoclimate were distinguished. Next, with the use of Landsat 8 and Terra satellite images, the DPN's land surface temperature (LST) was calculated. The estimation of LST using the distinguished types of topoclimate allowed for determining their degree of quantity diversification as well as assessing the differences between those types. The obtained LST values indicated statistically significant differences between the medians of LST values for almost all of the distinguished topoclimate types, thereby confirming the suitability of the applied topoclimate determination procedure.

1 Introduction

The concept of topoclimate is discerned between those of the mesoclimate and the microclimate (Paszyński et al. 1999). The spatial scale of the topoclimatic unit ranges from 100 m to 50 km (Oke 1987). Climatic diversification on the local scale follows from the nature of the exchange in momentum, heat, and matter between the earth's surface and the atmosphere (Paszyński et al. 1999; Oke 1987). The course of the abovementioned processes is dependent on the inclination of the slopes, height above sea level, relative height above the valley bottoms, and the physical features of the ground such as humidity, soil type, or vegetation (Oke 1987; Richards and Baumgarten 2003). Topoclimatic units are frequently typified

by strong spatial contrasts between the air and soil temperature, amount of precipitation, wind speed, snow melt, and rock evaporation or weathering indices.

Topoclimatic research may be conducted for forecasting purposes. Among other advantages, it makes it possible to plant crops in order—for example—to avoid losses connected with light freezes (Huang 1991; Kerdiles et al. 1996; Francois et al. 1999; Jarvis and Stuart 2001; Zinoni et al. 2002). In New Zealand, the implementation of “The Topoclimate South” project (1998–2001) has resulted in the drafting of maps on a scale of 1:50,000. One of them has presented growing degree-days, as well as other soil types. These maps have made it possible to determine the risk of occurrence of light freezes which are harmful to crops (South 2000; Richards and Baumgarten 2003). Similar studies were conducted in England and Wales by Jarvis and Stuart (2001) and in Italy's Emilia-Romagna region by Zinoni et al. (2002). In China, research there has focused on the impact of the topoclimate on citrus fruit cultivation (Huang 1991). In the Pampa region of Argentina (Kerdiles et al. 1996) and in the Bolivian Altiplano (Francois et al. 1999), satellite images have been used for the purpose of mapping the risk of extra seasonal light freezes. In all instances, landform and land cover have had a decisive influence on their occurrence.

✉ Marek Półrolniczak
marekpol@amu.edu.pl

Aleksandra Zwolska
aleksandra.zwolska@wp.pl

Leszek Kolendowicz
leszko@amu.edu.pl

¹ Department of Climatology, Adam Mickiewicz University in Poznań, Krygowskiego 10, 61-680 Poznań, Poland

Studies on road icing have also been conducted on a topoclimatic scale (Lindqvist 1976; Sugrue et al. 1983; Thornes 1985, 1991; Gustavsson 1995, 1999). Research has made use of mobile ground surface temperature measurement methods and the thermal mapping of two roads in Sweden, which indicate a close connection between landform and land cover on the one hand and ground surface temperature on the other. This made it possible to identify sections exposed to the risk of icing.

Topoclimatic research into the topoclimate's impact on fauna and flora is also being conducted. One example is the analysis of the impact of the topoclimate and land cover on the mountain butterfly population in the Iberian Peninsula (Illan et al. 2010). Among others, this has pointed to the predominant impact of topoclimatic factors on the spacing of species. In Australia, Ashcroft et al. (2012) have analyzed the potential location of microrefuges by means of precise topoclimatic grids. Their method has been successful in predicting the location of groups of codependent organisms of various species living in a specific type of environment. In Mexico, a study has been conducted on the wintering topoclimate of the monarch butterfly (*Danaus plexippus*) population (Weiss 2005).

One of the methods for classifying and mapping topoclimates is the Paszyński method (Paszyński 1980; Paszyński et al. 1999; Paszyński 2001). This one makes use of information concerning the structure of the energy balance in the active surface and the relative values of its individual components compared with values characterizing the standard surface (a flat area with an unobstructed horizon, covered with grass). In addition to Paszyński, both Kluge (1980) and Obrębska-Starkłowa (1980) have also occupied themselves with the methodology of topoclimatic mapping. Topoclimatic mapping is also the focus of works written by Grzybowski (1990) and Błażejczyk (2001).

The method proposed by Paszyński has been used for the purposes of topoclimatic mapping at the Słowiński National Park (Kolendowicz et al. 2001; Kolendowicz and Bednorz 2010). Topoclimatic research has also been conducted in the area of the Bieszczadzki National Park (Nowosad 2001). Kunert and Błażejczyk (2011) have studied the differences in air temperature on small areas with a diversified landscape.

In topoclimatic research, field studies are supplemented with satellite data, primarily for the purpose of determining the LST (Rao 1972). This is calculated using images from various sensors which scan the earth's surface (initially, these were provided, for example, by satellites [TIROS], while later on, data from early Landsat missions, MODIS, SEVIRI, ASTER, NOAA, and others have been used) (Pongracz et al. 2006; Stathopoulou and Cartalis 2007; Cheval and Dumitrescu 2009; Tan et al. 2010; Tomlinson et al. 2012).

The Paszyński method allows us to designate the spatial scope of selected topoclimate types; however, it does not give any information about the magnitude of their thermal

differentiation for the environmental conditions of the Drawa National Park (DNP). For this reason, the objective of the present study is to distinguish the topoclimate types occurring in the DNP so as to determine their spatial scope and degree of differentiation; and finally, to estimate the accuracy of the adopted procedure for designating topoclimates (selection and structure of digital maps) that applies the Paszyński method in conjunction with LST analysis.

2 Research area, data, and methods

2.1 Research area

The Drawa National Park (DNP) is situated in a sub-province of the South Baltic Lakeland. In Kondracki's (1998) division, this sub-province is divided into smaller units, with the area occupied by the DNP being part of the South Pomeranian Lakeland macro-region (Drawska Plain Mesoregion) (Fig. 1).

The topographic profile of the DNP comprises predominantly young-glacial outwash plains, which cover approx. 70% of its area; these are variegated with river valleys and lake basins. The highest point of the DNP is situated on the north (106 m a.s.l.), and the lowest in the southern part in the Drawa river valley (56 m a.s.l.) (Kondracki 1998).

The DNP is covered mainly with podzolic soils shaped by fluvioglacial and river sands. The podzolic soils are represented by two main soil types: rusty soils and podsols. The rusty soils in this region are the habitat of the Pomeranian beech, while the podsols support mixed forests. Brown soils cover no more than 3% of the DNP, occurring most frequently in areas of shallow boulder clays. These brown soils are usually overgrown with beech or beech and oak forests. Due to their fertility, in historic times, they were often utilized as arable fields (Biały 1998). The forests occupy more than 80% area of the DNP. Large swatches of the DNP are covered with Pomeranian and lowland beech in the form of mature forests, also with hornbeam and oak groves. Riparian forests are present in the river valleys, as are alder swamp forests and willow thickets. All types of peat bogs can be found in the DNP (Jasnowska 1998a). Eight rivers flow through the DNP. In the western part of the park, the main river is the Drawa. In the eastern part, the largest river is the Płociczna. The river valleys are characterized by diversified configurations, with numerous springs and well-heads along the river banks (Jasnowska 1998b). The DNP has fourteen water reservoirs with an area in excess of 1 ha; all are highly diversified (Choiński 2007). The lakes are located mainly in the eastern part of the DNP, along two specific lines. One of these lines is the valley of the River Płociczna, with flow-through lakes, whereas the second, which is parallel to the first, groups together closed-basin lakes (Kraska 1998).

Fig. 1 The research area: localization of DPN on a map of Poland and on the Landsat 8 image with DPN border

The area of the Drawa National Park has 1539 h of actual sunlight per annum and is characterized by an average annual air temperature of 8.1 °C. The lowest average temperature occurs in January (−1.5 °C), and the highest in July (17.6 °C). The average total annual sky cloudiness is 68%. The average annual sum of precipitation is 564 mm, with the lowest sums encountered in February (28 mm), and the highest in July (73 mm) (Woś 2010).

2.2 Data and methods

The analysis made use of both archival data and data obtained from cartographic databases such as Corine Land Cover 2012 (CLC2012) Copernicus, Corine Land Cover 2012, the Topographic Objects Database (BDOT), and the CGIAR-CSI (CGIAR Consortium for Spatial Information) database (CGIAR 2018). Use was also made of satellite data from the US Geological Survey (USGS) (USGS 2018).

The daytime temperature of the DNP's active surface was calculated on the basis of a satellite image from the Landsat 8 satellite, dated 7 June 2018, 9:48 UTC (11:48 CET). The nighttime temperature of the active surface was determined using a satellite image dated 4 May 2018, 20:44 UTC (22:44 local time); the photograph was taken by the ASTER sensor installed on the Terra EOS AM-1 satellite.

In order to obtain a topoclimatic map of the DNP, use was made of the procedure elaborated by Paszyński et al. (1999). This is an office method based on an analysis of the thermal energy exchange on the active surface during nighttime and daytime during the growing season. During that weather, all of energy fluxes are the biggest which causes that the differences of local climate are most visible. For this reason, detailed topographic, hydrological, soil, and other maps for a given area are mainly used to determine the range of individual topoclimate types. The method analyzes the structure and values of deviations from standard values in the individual components of the thermal balance equation of the active surface (Eq. 1), as measured on a flat surface covered with grass in windless and cloudless weather. In Paszyński's method, it was assumed that the energy fluxes reaching the boundary layer are denoted as positive and those emitting from it are negative.

$$Q + H + E + G + A = 0 \quad (1)$$

where

Q —all-wave net radiation, H —turbulent flux of sensible heat, E —turbulent flux of latent heat, and A —anthropogenic heat flux.

These deviations directly result from differences in landform (exposure and inclination of slopes, soil type, hydrographic conditions, and land cover). Paszyński's procedure distinguishes five types of topoclimate with further sub-types. Each type has different topographic conditions, water and soil relations, and, as a result, a different energy balance structure. The analysis is conducted for both daytime and nighttime. The two maps that present the exchange of energy on the active surface during a 24-h period are then used to create a map of the spatial scope of topoclimate types. The procedure for creating maps of energy exchange types for daytime and nighttime consists in executing office work that focuses on the analysis of a number of digital maps, i.e., a topographic map, land usage map, surface albedo map, hydrographic map, and a map of the land's roughness and humidity. In order to perform an analysis of landform, a hypsometric map was drawn up (digital elevation model, DEM) and used as the basis for creating a map of slope exposure and land inclination.

In order to calculate the temperature of the active surface during daytime, use was made of satellite photographs from the Landsat 8 satellite, which had been taken on 7 June 2018 at

9:48 UTC (11:48 local time). Bands 2–7 with a resolution of 30 m were used to carry out a classification of landform types, which was followed by the development of an emissivity map, wherein individual landform types were given emissivity values in accordance with the procedure proposed by Snyder et al. (1998). Further calculations were concerned with the conversion of at-satellite brightness temperature into land surface temperature. Calculations made use of data from one of the thermal ranges of a thermal infrared sensor (TIRS) spectrometer, channel 10 (10.6–11.2 μm), with a spatial resolution of 100 m. Calculations were then performed on the basis of the procedure presented by Weng et al. (2004).

All calculations were made using QGIS software with the GRASS plug-in and the Semi-Automatic Classification Plug-in (Congedo 2016).

The nighttime temperature of the active surface was calculated using a satellite photograph taken on 4 May 2018 at 20:44 UTC (22:44 local time). The photograph was taken by the ASTER sensor installed on the Terra EOS AM-1 satellite. Additionally, due to the failure of the SWIR sensor, use was made of 3 other satellite images, which made it possible to make a classification of the land cover and thereafter to create an emissivity map. The satellite photographs used for this purpose were taken on the following dates: 11 May 2002 at 10:02 UTC (12:02 local time), 11 May 2002 at 10:03 UTC (12:03 local time), and on 14 June 2006 at 10:07 UTC (12:07 local time). Bands 1–9 of the SWIR sensors, which were used to make the classification, are characterized by a spatial resolution of 30 m. In order to convert at-satellite brightness temperature to land surface temperature, use was made of band 13 (10.25–10.95 μm) of the TIR sensor with a spatial resolution of 90 m. Calculations were made using the QGIS software with the GRASS plug-in and Semi-Automatic Classification Plug-in (Congedo 2016). All satellite photographs were downloaded using the USGS EarthExplorer browser (USGS 2018).

In order to estimate the magnitude of the differences among individual topoclimatic units, and to determine the correctness of the method applied to distinguish these topoclimates, basic LST statistics were calculated and the appropriate statistical tests were performed. The existence of statistically significant differences for the median values was at first verified by taking all topoclimate groups into consideration simultaneously. However, this procedure only made it possible to determine the significance of differences without providing any information on the topoclimate pairs between which they occur, nor whether a given topoclimate is clearly different from the remaining area of the DNP. For this reason, the median values for a given topoclimate were also compared in pairs with the value of the median for the remaining area of the DNP, as were the values of LST medians between each pair of designated topoclimates. Based on the above, use was made of two non-parametric statistical tests, i.e., the Kruskal–Wallis test

jointly for all groups, and the Wilcoxon test to compare the pairs of variables (Wilks 2011). All statistical calculations were carried out using the R programming language (R Core Team R 2015) and its packages in support of the statistical and graphical techniques (Wickham 2016; Kassambara 2019; Wickham et al. 2019).

3 Results

3.1 Map of Topoclimates

The procedure for creating maps for the types of energy exchange during daytime and nighttime consists in executing office work that focuses on the development and analysis of

a number of digital maps, i.e., a topographical map, land usage map, surface albedo map, hydrographic map, and a map of the land's roughness and humidity. Additionally, a hypsometric map was drafted (digital elevation model, DEM) and used as the basis for creating a map of the slope's exposure and land inclination (Figs. 2 and 3).

In turn, the Corine Land Cover CLC2012 map (Copernicus, Corine Land Cover 2012) was used as the basis for creating the following: a map of the diversified types of land usage, a surface albedo map, and a map of the land's roughness. Further, a surface humidity map was created on the basis of a soil map of Poland, a hydrographic map, and maps connected with Poland's topographical profile. The hydrographic map was obtained on the basis of data from the BDOT. All of these maps

Fig. 2 Maps presenting land usage (a), surface albedo (b), surface roughness (c), soil humidity (d), and hydrography (e) within the area of the DNP

were created using the QGIS program (version 2.14.7), equipped with tools for creating, analyzing, and processing of GRASS spatial data (version 7.0.4).

Following the application of a procedure consistent with Paszyński's study (Paszyński et al. 1999), four types of energy exchange were distinguished for the DNP in daytime and three types at nighttime. These types of energy exchange occurring in both daytime and nighttime were used as the basis for distinguishing seven types of topoclimate (Table 1).

A topoclimate with positive deviations from the standard grass surface of the Q stream (type 1) is present in areas with positive H deviations at nighttime (energy loss on surface layer are supplemented by energy from the atmosphere) and the predominance of E during daytime (emitted energy is mainly used for evapotranspiration), meaning that the land is covered with vegetation. The summits of acclivities, upper sections of slopes, and areas with a southern exposure and slope inclination in excess of eight degrees were classified under type 1. This type of topoclimate is present near lake basins and river valleys in an area of approx. 490 ha, which accounts for 0.4% of the area of the DNP (Table 1; Fig. 4).

Type 2 topoclimates are present in areas with average deviation values of the Q energy stream during daytime. A subtype, 2.1.1, was distinguished under this type, with a predominance of the E stream due to vegetation coverage, as was another subtype, 2.2.1, due to the average H values during nighttime. These areas are either flat or with only a slight inclination not exceeding eight degrees, accounting for 9.3% and 79.4% of the DNP, respectively.

Topoclimates with negative Q deviations during daytime (3.1.1) were ascertained for areas with positive

deviations of the H stream during nighttime along with a predominance of the H stream during daytime. These are areas of slopes with a northern exposure and a slope inclination in excess of eight degrees located in the vicinity of lake basins and river valleys. The topoclimate with negative H deviations during nighttime (3.2) occurs in concave areas with a considerable ground humidity, vegetation, and a low albedo. These are locations where cool air gathers during the night, creating the so-called cold traps. Thus, topoclimate 3.2 was distinguished in river valleys, along lakes, and on areas with a small diversity of relative heights, which account for 3.8% of the DNP.

Topoclimate 4 is characterized by the positive values of the H stream during daytime, but which become negative at nighttime (during the day, the surface of the water is heated as a cooler by a stream of heat H from the air and at night as warmer than the air, it transfers a heat stream from its surface to the air lying above it). This type is closely associated with the presence of water reservoirs (6.8% of the area of the DNP). Its singular characteristic is the fact that during daytime, the H stream is directed from the atmosphere to the ground, whereas at nighttime, it is directed from the ground to the atmosphere, thus resulting in the radiation of energy gathered by water surfaces during the day.

The final topoclimate distinguished for the DNP is found present in the smallest part of its surface (0.2%). This topoclimate is associated with the presence of a stream of anthropogenic heat in the urbanized area of the township of Zatom (low-density development).

Fig. 3 DNP landform maps: hypsometric (a), slope exposure (b), and slope inclination (c)

Table 1 Share (%) of the distinguished topoclimatic units in the area of the DNP

Types of DPN topoclimates	Area (ha)	DPN area (%)
1. Topoclimates with positive Q deviations during day ($Q > Q_{st}$)	486.91	0.4%
1.1. Topoclimate with positive H deviations during the night $H > H_{st}$)		
1.1.1. Topoclimate with the predominance of E during the day ($ E > H $)		
2. Topoclimates with average values of Q during the day ($Q = Q_{st}$)	10,608.2	9.3%
2.1. Topoclimate with positive deviation of H during the night ($H > H_{st}$)		
2.1.1. Topoclimate with the predominance of E during the day ($ H > E $)		
2.2. Topoclimate with average values of H during the night ($H = H_{st}$)	90,243.5	79.4%
2.2.1. Topoclimate with the predominance of E during the day ($ E > H $)		
3. Topoclimates with negative deviation of Q during the day ($Q < Q_{st}$)	124.42	0.1%
3.1. Topoclimate with positive deviation of H during the night ($H > H_{st}$)		
3.1.1. Topoclimate with the predominance of E during the day ($ H > E $)		
3. Topoclimates with negative deviation of Q during the day ($Q < Q_{st}$)	4242.86	3.7%
3.2. Topoclimate with negative deviation of H during the night ($H < H_{st}$)		
4. Topoclimate with positive H values during the day and negative H values during the night	7672.39	6.8%
5. Topoclimate with the occurrence of A	275.79	0.2%
Total surface of DPN	113,654.01	100%

Q net all-wave radiation, H turbulent flux of sensible heat, E turbulent flux of latent heat, A anthropogenic heat flux, Q_{st} net all-wave radiation on the standard grass flat surface, H_{st} turbulent flux of sensible heat on the standard grass flat surface, $|H|$ and $|E|$ the absolute value of H and E

3.2 LST and topoclimate types distinguished for the DNP

This subchapter presents LST maps for selected daytime and nighttime, as well as histograms of their values, before proceeding to a characterization of the distinguished topoclimate types in terms of the LST value for both daytime and nighttime. Due to the skewed distribution of the frequency of LST value ranges, the authors have used henceforth the median instead of mean values.

During daytime (07.06.2018), the LST in the area of the DNP had values ranging from 20.2 to 36.3 °C, with a median of 21.9 °C. At nighttime (04.05.2018), the LST values were unsurprisingly lower, ranging from 1.8 to 16.0 °C, with a median of 8.1 °C. An analysis of the LST frequency histograms for daytime indicates that in the area of the DNP, the LST attained values in the range of 21–23 °C (nearly 90% of all values), while during nighttime, these ranged from 7 to 10 °C, accounting for more than 85% of the entire set of LST values (Fig. 5). The standard deviations in the LST values and variance for the analyzed datasets were also calculated. These totaled $std. = 1.42$ °C and $var. = 2.02$ °C for daytime and $std. = 1.8$ °C and $var. = 3.14$ °C for nighttime, which indicates more diversified LST values in the studied area for nighttime compared to daytime.

Taking into consideration the LST values occurring within the distinguished topoclimate types, the following are most readily distinguishable from observation: type 4, which occurs over water areas, and type 5, which is associated with areas indicating an anthropogenic heat stream (Fig. 6). The

first is characterized by the lowest LST values during daytime and the highest LST values at nighttime, in addition to their small variation. The LST median for water areas is some 5–6 °C higher than the median for all remaining types at nighttime, while during daytime, it is one of the lowest, amounting to a mere 21.4 °C. This phenomenon is quite obvious and results from the large thermal capacity of water, which far exceeds that of land surface. As a result, the highest (in daytime) and the lowest (at nighttime) LST values occur in the small urbanized area. This points to its low thermal

Fig. 4 Topoclimate types distinguished in the area of the DPN. Description of topoclimates according to Table 1

Fig. 5 Frequency of LST during the day (**a** 07.06.2018) and at night (**b** 04.05.2018)

capacity, which causes the ground to heat up fairly quickly during daytime and to cool down just as rapidly once the sun sets. It is also worth noting that the analyzed small township is located on a large forest clearing, which may account for the good conditions for cool air stagnation at nighttime, thereby conducive to a considerable fall in temperature during such a period (Paszyński et al. 1999).

The largest part of the DNP is covered by topoclimate type 2, which is present over flat areas or ones with only a slight inclination. Topoclimate 2.2.1 attains LST values close to the median both during daytime and nighttime, while topoclimate 2.1.1 is characterized by higher-than-average values of the LST median during daytime and lower values at nighttime. Topoclimates of this type (2.2.1 and 2.1.1) are characterized by higher LST values during daytime and lower LST values at nighttime compared to types 3.1.1 and 3.2, which is concordant with the adopted assumptions of the Paszyński method.

Certain doubts linger over the LST values attained during daytime concerning topoclimate 1.1.1, which should be characterized by the highest positive deviation in relation to the standard area. The values obtained are, however, lower than those calculated for the remaining topoclimates (Fig. 6; Table 2). At nighttime, they are thus concordant with

expectations. It may well be that the lower LST values during daytime for areas with topoclimate 1.1.1 are simply the result of the insufficient number of satellite photographs available for use in the study, not to mention the very small area occupied by this topoclimate type. The present observation also applies to the remaining distinguished topoclimate types that are characterized by the occupation of only a small area of the DNP.

Differentiation of the active surface temperature during daytime is relatively small for all topoclimate types, with the exception of types 4 and 5. Nevertheless, the statistical tests point to significant differences with regard to the values of LST medians. A Kruskal–Wallis test was carried out that simultaneously took all types into consideration, and which indicated their significant differentiation. The Wilcoxon tests were also conducted in order to check the significance of differentiation between all pair types and between the median for a given type of topoclimate on the one hand and the median for the remaining area of the DNP on the other. As for the topoclimate pairs, no significant statistical differences for daytime were determined for types 3.1.1 and 2.2.1 alone, and also for topoclimate type 3.1.1 and the median for the remaining area of the DNP. Such differences were present in all

Fig. 6 The LST in the Drawa National Park: during daytime (**a**)—on the basis of a satellite photograph from Landsat 8, taken on 7 June 2018 at 9:48 UTC, and during nighttime (**b**)—on the basis of a satellite photograph from the Terra satellite (EOS AM-1) via the ASTER sensor, taken on 4 May 2018 at 20:44 UTC

Table 2 The median, maximum, and minimum temperature of the LST (°C) in topoclimatic units distinguished in the area of the DNP during daytime and at nighttime

	LST	Topoclimatic units						
		1.1.1.	2.1.1.	2.2.1.	3.1.1.	3.2.	4.	5.
Day	Median	21.5	22.2	22.0	22.0	21.7	21.4	30.3
	Maximum	22.9	36.1	36.3	22.5	31.8	24.9	33.7
	Minimum	21.0	20.9	20.6	21.6	20.5	20.2	25.7
Night	Median	9.1	7.9	8.1	8.4	8.5	13.6	5.0
	Maximum	13.5	15.1	15.1	12.3	14.9	16.0	8.8
	Minimum	7.6	1.9	1.8	5.5	2.2	5.8	2.0

remaining instances (Fig. 6). In order to correctly interpret Fig. 6, it should be stressed that the broken line designates the median calculated for the entire area of the DNP for daytime and nighttime respectively, which cannot be equated with the value of the average temperature for the reference surface (a flat area overgrown with grass) being assumed for the purposes of the Paszyński method, and constitutes no more than an approximate value that is adopted for the purpose of testing the significance of the LST differences (Fig. 7).

4 Discussion and summary

The objective of this study is to distinguish the topoclimate types in the area of the DNP, determine their spatial scopes, and then assess the usefulness of the procedural algorithm applied and the method adopted to distinguish those

topoclimates. The research conducted has resulted in ascertaining seven types of local climate. The second part of the study attempted to estimate the LST for both daytime and nighttime based on the analysis of satellite photographs, before proceeding to an examination of whether the distinguished topoclimate types differ significantly in terms of LST values. It should, however, be taken into consideration that the results of the research concerning LST, as obtained from one set of photographs for both nighttime and daytime, may be used only for a very general and an initial characterization of the distinguished types of local climate.

LST differentiation is relatively small in the majority of topoclimates, with the exception of the anthropogenic topoclimate during daytime and nighttime and topoclimate associated with water areas during nighttime. Nevertheless, statistical tests indicate that in the majority of instances, the values of LST medians of individual topoclimates differ significantly with regard to the assessments of all groups simultaneously, pair comparisons of individual topoclimate types, and individual types in relation to the LST median for the entire area of the DNP. No significant statistical differences for daytime were determined between LST medians for types 3.1.1 and 2.2.1 alone, and also between LST median for type 3.1.1 and the median for the remaining area of the DNP. The above results allow us to state that the adopted procedural algorithm (selection and structure of digital intermediate maps) is useful for distinguishing the scopes of topoclimates in accordance with Paszyński's procedure.

When summarizing the research results in the form of maps showing the spatial scope of the distinguished topoclimate types or the differentiation in temperature

Fig. 7 Statistic of LST (°C) in DPN [a day time, b nighttime]) based on Landsat and Terra images according to established topoclimates (colors and order of types according to legend in Fig. 4). In the boxplot, the middle values denote the medians, the box extends to the Q1 (first quartile) and Q3 (third quartile), while the whiskers show a range of 99.3%: the upper whisker shows $Q3 + 1.5 \cdot IQR$ (the interquartile range), the

lower shows $Q1 - 1.5 \cdot IQR$. The notches extend to $\pm 1.58 \cdot IQR / \sqrt{n}$ and show 95% confidence intervals. The dashed line indicates the average LST value for DPN area. A pairwise comparison of Wilcoxon's different test codes: ns— $p > 0.05$; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; **** $p \leq 0.0001$

of the active surface during daytime and nighttime in the area of the DNP, we may note that the eastern and southern parts of the park are characterized by the maximum topoclimatic differentiation, which directly stems from a greater differentiation in the topography of this part of the research area. Furthermore, this area has a greater density of watercourses and water reservoirs in the forms of depressions, troughs, and hollows with no outlets.

The results of the topoclimatic mapping of the DNP supplement the existing body of knowledge on the climate of selected protected areas in Poland on a local scale. To date, similar research has been carried out in the Słowiński National Park (Bednorz et al. 2001; Kolendowicz and Bednorz 2010) and the Bieszczady National Park (Nowosad 2001). Similar studies on such small areas with a diversified landscape have also been conducted among others by Kunert and Błażejczyk (2011). The results obtained in those studies correspond to those put forward in the present work.

The impact of landform on the variability of temperature on the active surface is a general rule and the effect of this relation is very important in everyday life which is pointed out in many papers. The results obtained here are also consistent with the results of studies that analyzed the temperature of the active surface in the course of heat waves or cold waves in the Poznań agglomeration (Pórolniczak et al. 2018; Tomczyk et al. 2018), of research into the urban heat island in Poznań (Majkowska et al. 2017), and finally of LST research conducted in the city of Brno in the Czech Republic (Dobrovolny 2013). Furthermore, the elaborated analysis of differentiation in temperature of the active surface points to the impact of landform—and in particular of land depressions—on the spatial variability of ground and atmospheric temperature, which coincides with the results of research conducted in England and Wales into the influence of topographical variables and land cover on the maximum and minimum temperature (Jarvis and Stuart 2001). The results of this research are also concordant with those obtained by researchers who analyzed the risk of occurrence of light freezes that are harmful to crops—in Italy's Emilia-Romagna region (Zinoni et al. 2002), in China (Huang 1991), in the Bolivian Altiplano (Francois et al. 1999), and in New Zealand (Richards and Baumgarten 2003); these works all point to the significant impact of landform on the variability of temperature on the active surface. Finally, the results of the analyses performed in this study also coincide with those obtained by researchers who investigated the risk of occurrence of road icing, thereby demonstrating the significant impact of landform and land cover on the variability of temperature on the active surface (Lindqvist 1976; Sugrue et al. 1983; Thornes 1985, 1991; Gustavsson 1995, 1999).

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