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NET SOLAR RADIATION IN THE SOUTHERN PART OF THE KRAKÓW-CZĘSTOCHOWA UPLAND IN THE PERIOD OF 2008-2014

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Abstract: The objective of this study was to determine the net shortwave solar radiation (K*) on a plateau and the bottom of a canyon in the southern part of the Kraków-Częstochowa Upland. Its significant diurnal and annual variability was expressed as hourly, daily, monthly, seasonal and annual totals of K*. The great diversity of the terrain, varied forms, expositions and slopes, considerable denivelations, and also the diversity of the land cover and land use make this small area very diversified as far as radiation conditions are concerned. On the basis of the actinometrical study, the differences of radiation were assessed on two distinct morphological terrain forms: on the plateau and on the bottom of the canyon. The mean daily value of the total of K* amounted to 10.8 MJ m^{-2} on the plateau, and to 9.1 MJ m^{-2} on the bottom of the canyon in the analysed period.

Keywords: net solar radiation, effective radiation, topoclimate, the Kraków-Częstochowa Upland

INTRODUCTION

The net solar radiation (K*), also known as effective radiation, is the difference between the total solar radiation (K↓) and the reflected radiation (K↑). It is extremely important for the formation of the climatic conditions of the area, as it affects the processes taking place in the superficial active layer, the energy balance, and therefore the thermal and humidity relations between the subsurface layers of the atmosphere and its substratum (Oke 1999, Paszyński 2004, Kossowski 2005, 2007, Steinacker *et al*. 2007, Bryś 2009, Hoch *et al*. 2010). For these reasons, in the study of climate it is very important to recognise the components and structure of the net solar radiation of the active surface.

The research and modelling of the solar radiation in the Kraków-Częstochowa Upland exhibited a high spatial variability of its distribution (Caputa 2001, Wojkowski and Caputa 2009a, 2016a, Caputa 2016a). High relief of the terrain, variety of forms, exposure and inclinations, as well as considerable differences in altitude result in the fact that on a relatively small area there is a significant diversity of insolation conditions and of the structure of the radiation balance (Caputa and Wojkowski 2015). This affects the formation of the temperature (Clemens *et al*. 2003), thermics of the active surface (Caputa and Wojkowski 2013), limestone rocks (Brzeźniak 2001, Caputa 2016b), the presence of snow (Wojkowski 2009), temperature inversion (Whiteman *et al*. 2004, Niedźwiedź 2009), etc. This brings about microclimatic contrasts (Bokwa *et al*. 2006, Caputa 2009), formation of various topoclimates (Klein 1992, Bokwa *et al*. 2008, Bartuś 2014), which, in turn, is correlated with indigenous vegetation (Sołtys-Lelek 2009, Bárány-Kevei 2011) and biodiversity (Wołowski *et al*. 2004) in karst areas.

The subject of this study is the variability of the net short-wave solar radiation in the southern part of the Kraków-Częstochowa Upland in the period of 2008-2014, whereas the aim is to identify factors affecting the net K* for specific sites: the plateau and the bottom of the canyon.

MATERIAL AND METHOD

The study area is located in the Ojców National Park situated in the southern part of the Kraków-Częstochowa Upland (Fig. 1). This area has high relief, and is characterised by diversification of forms, exposure and inclinations, significant differences in altitude and exposed rock formations (Gradziński *et al*. 2008). Two groups of forms are identifiable in this relief, i.e. plateau and canyon. These geomorphological forms exert the greatest impact on the conditions of the local climate (Caputa and Partyka 2009). The data employed in the study were collected at the meteorological station located on the plateau, in the village of Lepianka Czajowska (LCz – plateau characterised by the geographic coordinates of 50°12′23″N 19°47′04″E, altitude of 483 m a.s.l.). The station is situated on a flat area, with an insignificant horizon obstruction (2%, mainly to the west), and well represents the climatic conditions of the highest part of the Kraków-Częstochowa Upland (Caputa and Leśniok 2009). The other station of Park Zamkowy in Ojców (PZ – canyon characterised by the geographic coordinates of 50°12′35″N 19°49′44″E, the altitude of 322 m a.s.l.) is located on the bottom of the narrow (50-150 m), deep (more than 100 m) valley of the river Prądnik, with the general course from the north to the south. The horizon obstruction is considerable (10-35°) due to the steep slopes of the eastern and western exposure and trees. Such a location of the station reflects the specificity of the deep canyons of the Kraków-Częstochowa Upland which exhibit the character of canyons, and well represents the climatic conditions of concave landforms (Caputa and Partyka 2009).

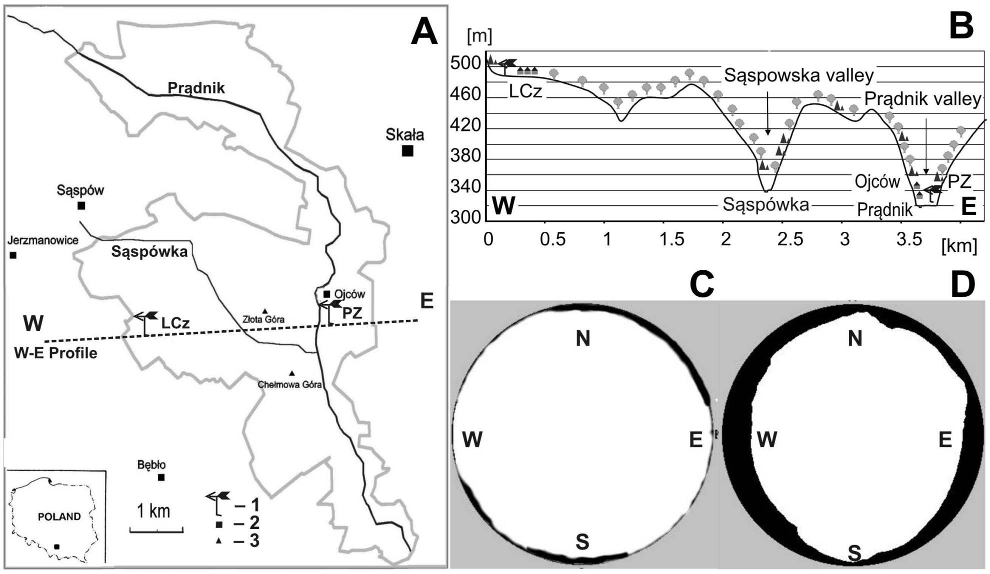

Fig. 1. Location of the meteorological stations (A) in the profile of the study area (B) and obstruction horizon on the plateau at Lepianka Czajowska (C) and on the bottom of the canyon in Ojców (D). 1 – meteorological station, 2 – villages, 3 – hill-tops

Both of the stations, apart from recording basic meteorological components, also carry out the measurements of radiation balance components with the employment of CNR1 (Kipp&Zonen) at the height of 1.5 m above the ground. The measurements were performed within 10 s intervals and recorded with CR1000 (Campbell) as 10 minutes' averages. The fluxes of K↓ and K↑ were measured with CM3 pyranometer (305-2800 nm) with measurement error of 6% (–10÷40°C) and ±25 W m^{-2} at 1000 W m^{-2}. The CNR1 sensor (consisting of two CM3 and two CG3) was periodically calibrated through comparing it to the CNR1 and CNR4 (a new one certified by Kipp&Zonen) working at the station of the Faculty of Earth Sciences in Sosnowiec.

For the purpose of the analysis, the data series from the years of 2008-2014 were employed. Missing data from the LCz station were supplemented by the measurements from the PZ station (using regression equations and taking into account the time of day and the year). The values of the totals of K* were presented in UTC time (official summer time = UTC +2 hrs). The average solar noon in the area is at approx. 10:39 UTC. Thus prepared 32939 values of the hourly totals of K↓ and 2557 values of the daily totals of K* were analysed with the Statistica program. The distribution of the variables was different from the normal distribution. The flux K* was substantially variable during the day and the year due to the position of the Sun.

Due to the distribution of the variables of the radiation totals, different time intervals (hourly, daily, monthly, seasonal and annual) were taken into account, which constituted the basis for determining the amount and variability of the effective radiation absorbed by the plateau parts (LCz) and the bottom of the canyon (PZ) as the characteristic forms of the Kraków-Częstochowa Upland.

RESULTS

Hourly totals of the net solar radiation

As a result of the analysis of the hourly totals of net K*, the frequency in the intervals of 0.5 MJ m^{-2} h^{-1} was calculated to identify the distribution of the values recorded in the period of 2008-2014. The vast majority of the values of the hourly totals of K* fall into the range of 0-0.5 MJ m^{-2} h^{-1} (53.7%), whereas only 1.5% of the totals of K* were greater than 2.5 MJ m^{-2} h^{-1} in the open space of the plateau. On the bottom of the canyon the values observed in the aforementioned range/interval were 5.7% higher, while the totals of K* above 2.5 MJ m^{-2} h^{-1} were 1.2% lower (Tab. 1). This resulted mostly from the limited supply of radiation to the bottom of the canyon due to its shading by the slope.

Table 1. The percentage of the hourly totals of K* at LCz and PZ stations in the period of 2008-2014

Stations	K* (MJ m^{-2} $hour^{-1}$)					
	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	> 2.5
LCz – Plateau	53.7	17.6	11.6	9.4	6.2	1.5
PZ – Canyon	59.4	14.7	11.4	9.2	5.0	0.3

The highest mean total K* of 1.1 MJ m^{-2} h^{-1} in the analysed multiyear period was observed within the interval of 10:10-11:00 at LCz station. The equivalent total of K* on the bottom of the canyon was 0.1 MJ m^{-2} h^{-1} lower. Within the same time interval, the maximum of K*, amounting to 2.9 MJ m^{-2} h^{-1}, was recorded at LCz station on 6.07.2008. It was associated with the ascendancy of the Sun (10:39 UTC), lack of cloud cover and high air transparency. The distribution of the mean hourly totals of K* demonstrated the effect of the horizon obstruction and the reduction of the flow of radiation to the bottom of the canyon due to the high humidity and frequent fog in the terrain depression (Fig. 2). There was also observed an asymmetry of the distribution of radiation because of the overcast sky. However, much greater impact on the reduction of radiation K* was exerted by the relief of the deeply incised canyon causing the horizon obstruction by the slopes (especially form E and W directions). Therefore, a decreased operation of the Sun in the canyon, and therefore lower totals of K*, were recorded in the morning and evening hours (Fig. 3).

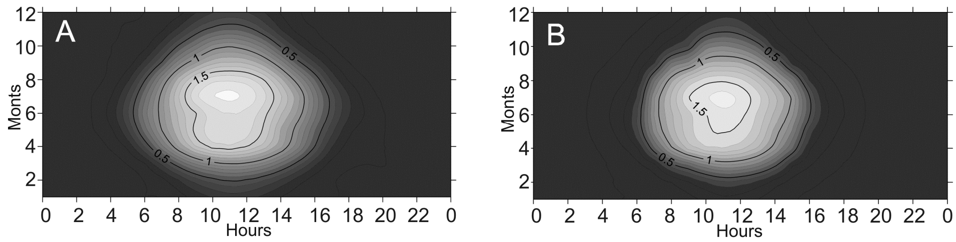

Fig. 2. Mean hourly totals of K* (MJ m^{-2}) at LCz (plateau) meteorological station (A) and PZ (canyon) station (B) in 2008-2014

Table 2. The percentage of the daily totals of K* at LCz and PZ stations in the period of 2008-2014

Stations	K* (MJ m^{-2} day^{-1})					
	0-4	4-8	8-12	12-16	16-20	> 20
LCz – Plateau	37.0	17.5	12.4	13.3	11.5	8.1
PZ – Canyon	44.2	17.5	14.5	14.0	8.9	0.9

Daily totals of net solar radiation

In the open area of the plateau, the vast majority of the values (54.5%) of the daily totals of K* were below 8 MJ m^{-2} d^{-1} and merely 8.1% were above 20 MJ m^{-2} d^{-1}. In the corresponding ranges on the bottom of the deeply incised canyon, exhibiting the character of the canyon, the percentage points of the daily totals of K* amounted to 61.7 and 0.9%, respectively (Tab. 2). Values of the daily total of K* above 12 MJ m^{-2} d^{-1} occurred from 28 March to 5 October, and were observed for 167 to 207 days of the year on the plateau, which points to a relationship with the vegetation season in the area. A significantly shorter period, from 27 March to 13 September, was characterised by analogous values of the totals of K*, and was observed for 140 to 171 days per year in the canyon (Fig. 4). The highest daily total of K* of 26.3 MJ m^{-2} d^{-1} was recorded on 13.06.2013. whereas a value close to zero – on 28.01.2009 at LCz station. On the same days, the extreme values of the totals of K* (21.5 MJ m^{-2} d^{-1}) were recorded at PZ station. This was the effect of strong absorption of radiation by the grassy surface in summer, whereas in winter, owing to the fact that short-wave radiation is reflected from the bright surface of snow, the absorption of radiation was significantly limited.

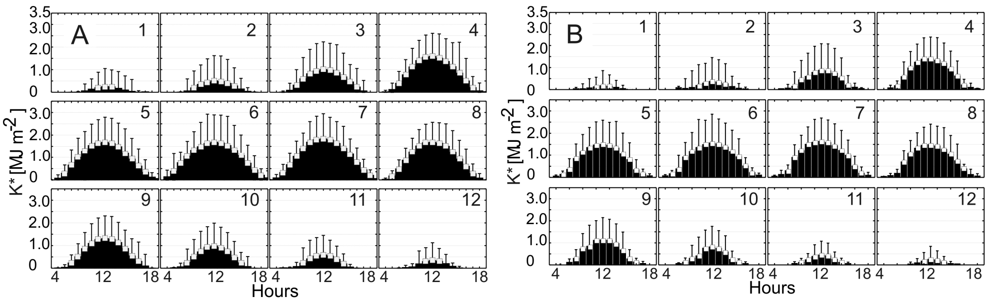

Fig. 3. Mean hourly totals of K* categorized according to months on the plateau (A) and the bottom of the canyon (B) in 2008-2014. The square indicates the average value, the dashed lines mark the maximum

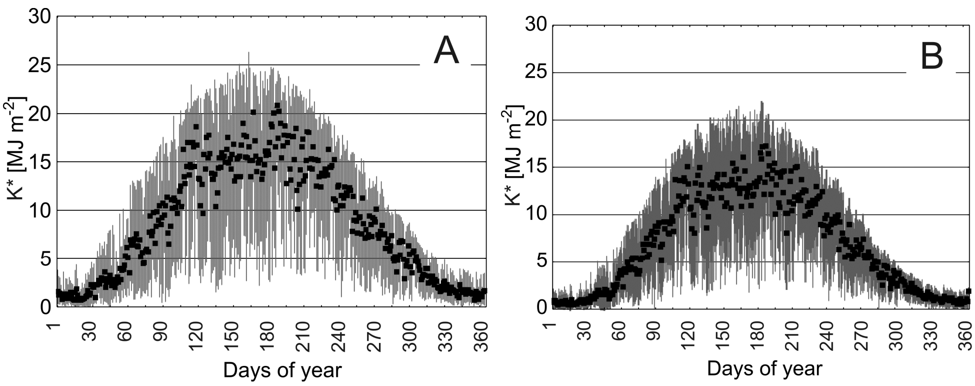

Fig. 4. Mean daily totals of K* on the plateau (A) and the bottom of the canyon (B) in 2008-2014. The square indicates the average value, the dashed lines mark the extremes

In the monthly distribution of the mean daily totals of K*, the months from April to September were distinguishable at LCz station, whereas at PZ station the values exceeded 8.0 MJ m^{-2} d^{-1} only from April to September (Fig. 5). These periods were closely linked with the vegetation season, when effective radiation was utilised in life processes of the plants. The highest mean analysed total of K* was calculated for July – 16.3 MJ m^{-2} d^{-1}, while the lowest for January – 1.2 MJ m^{-2} d^{-1} on the exposed surface of the plateau. Due to the relief of the canyon, much lower values were noted in July (13.3 MJ m^{-2} d^{-1}) on the bottom of the canyon, and in December (0.7 MJ m^{-2} d^{-1}) radiation was additionally limited by fog and haze. In terms of seasons, higher mean daily totals of K* were characteristic for the spring and summer, amounting to 11.3 and 15.2 MJ m^{-2} d^{-1} at LCz station and 9.2 and 12.5 MJ m^{-2} d^{-1} at PZ station, respectively (Fig. 6). Much lower values of the analysed totals of K* occurred during the autumn and winter because of the low position of the Sun above the horizon, shorter days, and increased cloudiness and haze in comparison with the spring and summer. Obstruction of the horizon by the slopes and the vegetation growing on the slopes and the bottom of the canyon was an additional important factor limiting the flow of radiation to the concave landforms.

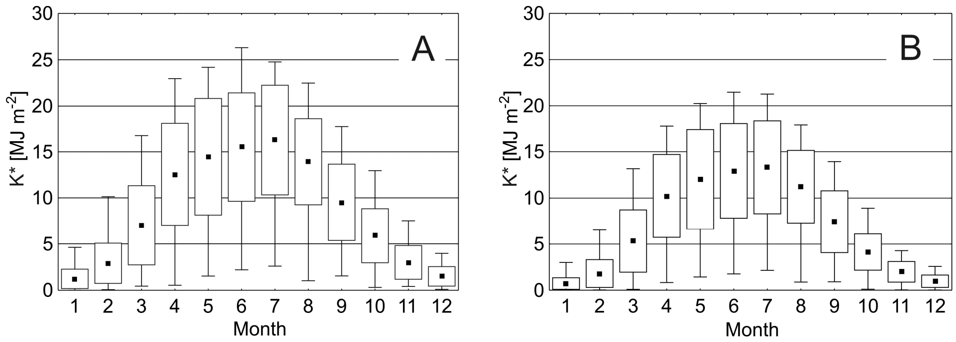

Fig. 5. Mean daily totals of K* categorized according to months on the plateau (A) and the bottom of the canyon (B) in 2008-2014. The square indicates the average value, the frame stands for the standard deviation from the average value, while the dashed lines mark the extremes

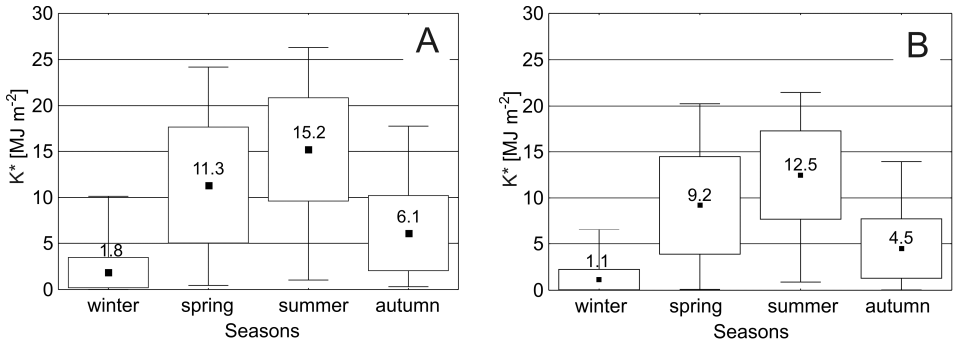

Fig. 6. Mean daily totals of K* categorized according to the seasons on the plateau (A) and the bottom of the canyon (B) in 2008-2014. The square indicates the average value, the frame stands for the standard deviation from the average value, while the dashed lines mark the extremes

The annual course of effective radiation in the Kraków-Częstochowa Upland was as follows: in the winter months, the values were low, whereas in March, when the snow had melted, there was a sharp upsurge in the values. In the months that followed, a rapid increase resulted in their reaching the maximum in July. Starting from August, they decreased gradually until reaching the minimum in the winter months.

The mean annual daily total of K* was 8.7 MJ m^{-2} d^{-1} on the plateau in the analysed multiyear period; the highest was 9.2 MJ m^{-2} d^{-1} in 2012, and the lowest 7.9 MJ m^{-2} d^{-1} in 2010. The average value of the daily total K* on the bottom of the canyon was 6.9 MJ $m^{-2}d^{-1}$ in the analysed period; the highest value – 7.2 MJ m^{-2} d^{-1} in 2012, and the lowest – 6.3 MJ m^{-2} d^{-1} in 2010. These values were on average 21% lower than those measured on the plateau.

Monthly totals of net solar radiation

The compilation of the monthly totals of K* allowed a more general assessment of the radiation relationships in the annual course in the years 2008-2014 (Fig. 7). Low mean monthly totals of K* occurred at the analysed stations in January and in December, whereas the highest in July. This was closely related to the position of the Sun above the horizon and to the length of the day. At LCz station, in the course of the totals of K*, a significant inflow of radiation to the active surface was observed in the spring months, e.g. the total of K* for April 2009 (506 MJ m^{-2}) exceeded the total of K* for June (408 MJ m^{-2}) and August (469 MJ m^{-2}). It should be noted that June 2009 was exceptionally cloudy and rainy, which resulted in values significantly lower than the mean total of K* at LCz station, which was 466 MJ m^{-2} $month^{-1}$ for the period of 2008-2014. The calculated mean monthly total of K* for May had a high value of 449 MJ m^{-2} $month^{-1}$. However, the month of May was characterised by a high variability of insolation conditions in the aforementioned total of K*, from the minimum (298 MJ m^{-2}) in 2010 to the maximum (533 MJ m^{-2}) in 2012 at LCz station. Slight variations and amplitudes of the monthly totals of K* were observed in November and in the winter months. The highest analysed total of K* of 567 MJ m^{-2} was recorded in July 2009, while the lowest – 14 MJ m^{-2} – in January 2010 on the plateau.

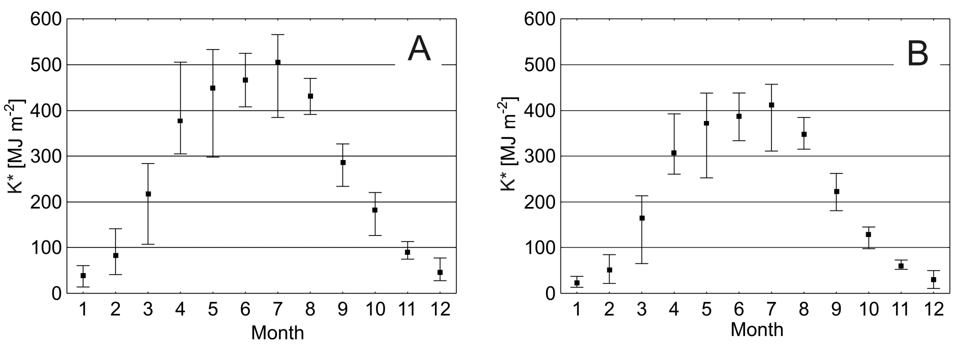

Fig. 7. Mean monthly totals of K* on the plateau (A) and the bottom of the canyon (B) in 2008-2014. The square indicates the average value, while the dashed lines mark the extremes

In the course of the mean monthly totals of K*, a significant inflow of radiation to the active surface of the canyon was noted in the spring months (Fig. 7B), e.g. the mean monthly total of K* reached a high value of 378 MJ m^{-2} in May. The highest value of K* equal to 457 MJ m^{-2} was recorded in July 2013. whereas the lowest of 11 MJ m^{-2} – in December 2010 at PZ station. Minor variations in monthly totals of K* were observed in November and in the winter months. These values were significantly lower than the values measured on the plateau due to the shortened time of operation of the Sun. This time was especially reduced at the time of a low position of the Sun in the winter months. During this period, the bright surface of snow additionally reflected the total radiation (large incidence angle), thus minimising the totals of K*.

Annual totals of net solar radiation

At the station on the plateau, the minimum annual total of K* had the value of 2870 MJ m^{-2} in 2010, whereas the maximum – 3335 MJ m^{-2} in 2012. The mean annual total of K* for the period of 2008-2014 was 3170 MJ m^{-2} $year^{-1}$. The lowest annual total of K* on the bottom of the canyon was 2313 MJ m^{-2} in 2010, while the highest amounted to 2625 MJ m^{-2} in 2012. The mean annual total of K* reached 2500 MJ m^{-2} y^{-1} for the studied period. This value was 21% lower than the mean annual total of K* for the same period, measured on the plateau of the Kraków-Częstochowa Upland. The main reason for this fact was the significant obstruction of the horizon in the deep canyon, the bottom of which is located 161 meters below the station on the plateau (Fig. 1).

DISCUSSION

The amount of solar radiation absorbed by the active surface and transformed into other forms of energy is directly dependent on the amount of the total solar radiation incoming to the surface, and short-wave radiation reflectivity of the surface (Paszyński and Niedźwiedź 1999). The diverse terrain relief and heterogeneity of the vegetation of the Kraków-Częstochowa Upland lead to a distinct spatial differentiation of the amount of solar energy absorbed by the Earth's surface (Wojkowski and Caputa 2009b). The tabulated data point to the monthly variation and large contrasts between the plateau and the canyon resulting from these factors (Tab. 3). The large contrasts of the insolation conditions in this area have been confirmed by spatial modelling (Wojkowski and Skowera 2011).

High positive differences between the measured and modelled values were obtained for the months of May and June. Therefore, the high values of the analysed totals of K* measured on the plateau are the result of the inflow of the flux

K↓ unrestricted by any obstacles (trees, buildings, etc.) (Caputa and Wojkowski 2016b). The higher values were measured in the spring and summer months because of the high position of the Sun above the horizon and the length of the operation of the sunlight, while the lower totals of K* were recorded in the autumn and winter. This was in line with the higher values of the inflow of K↓ to the southern part of the Kraków-Częstochowa Upland (Caputa 2015a,b). This is confirmed by the tabulated per cent ratio of the totals of K* to the totals of K↓ (Tab. 4). On the plateau, this ratio ranged from 82 to 85% during the vegetation season due to the lack of snow cover, whereas it was significantly lower in winter when snow cover was present (80%) – after T. Kozłowska-Szczęsna (1973). At the same time, lower percentage points were calculated for the bottom of the canyon. On average, for the year it was a value about 5% lower than the value on the plateau. In addition, the convex landforms of the Kraków-Częstochowa Upland were characterised by lower humidity, as well as by less frequent fog and mist in comparison with the concave landforms (Caputa 2009). Moreover, higher wind speeds on the plateau (Brzeźniak and Partyka 2008) contributed to an increase in the transparency of the air and thereby increased the radiation flux. The maximum values of the hourly and daily totals were measured on clear, cloudless days.

Table 3. Mean monthly and annual totals of K* (MJ m^{-2}) on the plateau (LCz) and the bottom of the canyon (PZ) and the differences between PZ and LCz in 2008-2014

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
LCz – plateau	38	82	218	377	449	466	505	431	285	183	90	46	3170
PZ – canyon	23	51	165	305	372	387	412	347	222	128	59	30	2500
PZ – LCz	–15	–31	–53	–71	–77	–79	–93	–84	–63	–55	–31	–17	–670
K_m* – modelled	45	82	221	360	487	506	491	397	259	129	50	28	3055
K_m* – LCz	7	0	3	–17	38	40	–14	–34	–26	–54	–40	–18	–115
K_m* – PZ	22	31	56	55	115	119	79	50	37	1	–9	–2	555

K_m* – modelled monthly values of K* in ONP / monthly values of K* in the Ojców National Park calculated with the employment of the empirical model (Wojkowski and Skowera 2011)

Table 4. Per cent ratio of monthly and annual totals of K* to K↓ (%) on the plateau (LCZ) and the bottom of the canyon (PZ) and the differences between PZ and LCz in the years of 2008-2014

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
LCz – plateau	46	52	72	82	82	83	85	84	84	83	82	65	80
PZ – canyon	36	43	69	79	79	80	79	78	79	78	76	57	75
PZ–LCz	–10	–9	–2	–4	–4	–3	–6	–5	–4	–5	–6	–9	–5

The much lower values of K* calculated for the bottom of the canyon resulted mainly from the lower influx of K↓ (Caputa 2016a). Therefore, the differences of the totals of K* between the canyon and the plateau were the greatest in the summer, and in the annual total they amounted to 670 MJ·m^{-2} (Tab. 3). The spatial modelling of K* indicates the lowest values of radiation on the bottoms of canyons, in depressions of the terrain, on the northern slopes of canyons due to shading (Wojkowski, Caputa 2015). In addition, canyons of the meridional course are more shaded than those of the latitudinal course (Klein 1992, Caputa 2015b). This is of particular importance in areas of diverse relief in early morning and late afternoon, when the position of the Sun is low (Whiteman *et al*. 1989, Baranowski 2003, Gądek and Caputa 2003).

Physical properties of the surface (e.g. moisture, vegetation cover), its shape and incidence angle (Bailey *et al*., 1999), constitute another factor which determines the intensity of K*. It is particularly important in karst conditions, where the proximity of rock walls may increase its values because of the bright surface of high-reflectivity (Caputa 2016b). Reflectivity varies significantly according to the type of the natural surface. In the case of bare soil, solar radiation is absorbed only by a thin upper layer (Paszyński *et al*. 1999), while limestone or the surface of snow highly reflect radiation. Moreover, the values of albedo were influenced by the phase of the plant growth and affected the total of K* (Tab. 3 and 4). These correlations are spatially reflected in satellite images by the variety of the landforms (Wojkowski and Caputa 2009b). An average albedo modelled for the study area was 20%, the lowest in the autumn – up to 12%, and the highest for long-lying snow – more than 60%. The highest albedo recorded in the satellite photo was characteristic of limestone rock – 24% in spring, slightly lower in summer (23%) and 18% in autumn (Wojkowski and Caputa 2009c). The maximum was noted for snow (86%) and much lower for grass (21%), and at bare soil even 12% (Bryś 2013).

The measured daily totals were 0.95 MJ m^{-2}d^{-1} higher than those reported in the past for the Kraków-Częstochowa Upland as the daily mean total of K* of 7.75 MJ m^{-2} d^{-1} was reported for the period of 1956-1975 (Grzybowski *et al*. 1994). The cited authors distinguish the vegetation period (IV-X) and report the mean daily total of 11.25 MJ m^{-2} d^{-1} which is 1.35 MJ m^{-2} d^{-1} lower than the value measured on the plateau. Lower values were also reported in earlier works (Paszyński 1966, Kozłowska-Szczęsna 1973). Higher radiation measured on the plateau can be attributed to the global brightening (e.g. Wang *et al*. 2013). Part of the work shows a strong upward trend of measured solar radiation, even 0.87 W m^{-2} in the period of 1982-2008 (Wang *et al*. 2012).

The maximum annual radiation K* occurred in July, when its monthly totals exceeded 505 MJ m^{-2} on the plateau and 412 MJ m^{-2} in the canyon. Values 3 MJ m^{-2} lower were reported by Kozłowska-Szczęsna (1973), whereas the data comprised in the Atlas of the radiation balance in Poland (Paszyński 1966) were

5-10% lower. In the cold period, the influence of snow cover on the values obtained was significant, as bright surfaces absorb small amounts of energy.

The measured values of radiation allowed validating models of the spatial variability of the intensity of K* and constructing maps of actual distribution of radiation (Wojkowski and Skowera 2011). In addition, the quantitative compilation of the totals of K* has laid the foundations for further detailed analysis of the climatic, microclimatic, biological and ecological conditions of the environment of this part of the Kraków-Częstochowa Upland.

CONCLUSIONS

The compilation of the intensity of the net short-wave solar radiation in the form of hourly, daily, monthly, seasonal and annual totals allowed determining the variability of the radiative conditions of the open plateau surface and the deeply incised canyon in the southern part of the Kraków-Częstochowa Upland.

On the basis of the measurements of radiation at the station of Lepianka Czajowska (plateau) and Park Zamkowy (canyon) in Ojców in the period of 2008-2014, the following differences in the totals of K* were observed:

1. The highest mean hourly total of K* of 1.1 MJ m^{-2} h^{-1} was noted in the canyon for the interval 10:10-11:00 UTC. Within the same time interval, the maximum of K* of 2.9 MJ m^{-2} h^{-1} was recorded on the plateau on 06.07.2008.

2. The highest daily total of K* of 26.3 MJ m^{-2} d^{-1} was measured on 13.06.2013 on the plateau, whereas the value on that day on the bottom of the canyon was 18% lower.

3. The months from April to August were distinctive because of a high mean daily total of K* – the highest of 16.3 MJ m^{-2} d^{-1} in July and the lowest of 1.2 MJ m^{-2} d^{-1} in January on the plateau, and 13.3 and 0.7 MJ m^{-2} d^{-1}, respectively, on the bottom of the canyon.

4. The average value of the daily total of K* was 8.7 MJ m^{-2} d^{-1} at the exposed LCz station, and 6.9 MJ m^{-2} d^{-1} at the PZ station in the deep canyon.

5. The mean annual total of K* was 3170 MJ m^{-2} y^{-1} at LCz station and 2500 MJ m^{-2} y^{-1} at PZ station for the studied period.

The foregoing differences resulted from the fact that the stations were located at characteristic points (plateau and canyon) in a high-relief karst terrain of the Kraków-Częstochowa Upland. On the bottom of the deeply incised canyon, the surface absorbs on average 21% less radiation than in the open air on the plateau. This percentage ranged from 18% in January to 40% in July. The main reason for this fact was that the supply of total radiation was reduced by the mountains, slopes and vegetation on the walls of the canyon. This has been confirmed by substantial obstruction of the horizon at the measuring point on the bottom of the canyon.

Therefore, in the areas situated on the bottom of the canyon, unfavourable insolation conditions prevailed (especially in the period from October to March). In addition, longer duration of snow cover in the winter than on the plateau was another factor which reduced the totals of K* on the bottom of the canyon.

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SALDO PROMIENIOWANIA SŁONECZNEGO W POŁUDNIOWEJ CZĘŚCI WYŻYNY KRAKOWSKO-CZĘSTOCHOWSKIEJ W OKRESIE 2008-2014

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Streszczenie: Przedmiotem badań było saldo promieniowania słonecznego (K*) na wierzchowinie i na dnie kanionu w południowej części Wyżyny Krakowsko-Częstochowskiej. Zmienność dobową i roczną K* wyrażono jako sumy godzinne, dzienne, miesięczne, sezonowe i roczne w okresie 2008-2014. Duża różnorodność terenu, zróżnicowane formy, ekspozycje i stoki, duże deniwelacje, a także różnorodność pokrycia terenu i użytkowania gruntów sprawia, że ten krasowy obszar ma zróżnicowane warunki insolacyjne. Wykazano dużą zmienność salda K* oraz jego uwarunkowanie ze względu na zasłonięcie horyzontu przez strome ściany kanionu. Różnice promieniowania pochłoniętego oceniano dla dwóch różnych form morfologicznych: wierzchowiny i dna kanionu. Średnia dzienna wartość sumy K* w analizowanym okresie wyniosła 10,8 $MJ \cdot m^{-2}$ na wierzchowinie i 9,1 $MJ \cdot m^{-2}$ na dnie kanionu. Analogicznie do wymienionych form terenowych średnie roczne sumy K* dla analizowanego okresu wyniosły 3955 i 3312 $MJ \cdot m^{-2}$.

Słowa kluczowe: promieniowanie słoneczne, saldo promieniowania, promieniowanie pochłonięte, topoklimat, Wyżyna Krakowsko-Częstochowska