GLOBAL RADIATION AND ALBEDO IN THE RADIATION SYSTEM OF LAKE BALATON

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Abstract

The values of global radiation and albedo measured above Lake Balaton between July 2007 and August 2008 were examined and that was compared with the global radiation measured above the standard meteorological station of Keszthely. Different intensity of global radiation was found above the shore and above the water at the same elevation of the Sun. At low elevations the global radiation is higher above the shore while at solar elevation beyond 40° it is higher above the water. In 90 % of the examined period the values of albedo measured in the morning differed from that measured in the afternoon at the same elevations. The difference increases with the decrease of solar elevation. In summertime until the middle of September the albedo measured in the morning is regularly higher than that measured in the afternoon. From

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the middle of October the values measured in the afternoon are higher. The mean albedo of the Lake Balaton is the smallest in June: 3-5%, thereafter it rises gradually. The mean albedo was 6.8% at Keszthely Bay, in the course of our investigation.

Key-words: albedo, Balaton, global radiation, reflected radiation, Keszthely Bay

Összefoglalás

A Balaton hőháztartásának legfontosabb komponense vízfelület által abszorbeált elektromágneses sugárzás. Jelen tanulmányban a tó felett mért globálsugárzás és albedó értékeket vizsgáltuk 2007 júliusától 2008 augusztusáig, illetve a víz felett és a standard meteorológiai állomáson mért globálsugárzást hasonlítottuk össze. Vizsgálataink technikai alapját képezi, hogy 2007-ben a Balatoni Integrációs Kht. két hidrometeorológiai paramétereket rögzítő mérőoszlopot telepített a Balaton parttól távolabbi tó-testébe. Az egyiket Siófok közelébe, a másikat pedig a Keszthelyi-öbölbe. Jelen tanulmányhoz felhasznált adatok mérése a Keszthelyi öbölben, a parttól 1000 méterre történt a vízfelület felett 3 m magasságban. A szárazföld feletti sugárzásadatok a keszthelyi Agrometeorológiai Kutatóállomás bocsátotta rendelkezésünkre.

A parton és a víz felett ugyanolyan napmagasság mellett különböző intenzitású globálsugárzást figyeltünk meg. Alacsony napállásnál a parton, 40°-nál magasabb napállásnál a víz felett erősebb a globálsugárzás. Szeptembertől, amikor a nap delelési magassága nem éri el a 45°-ot, egész nap a szárazföld fölött mértük a nagyobb értékeket. A napi összes globálsugárzásban a nyári hónapokban nem mutattunk ki szignifikáns eltérést, mivel a víz felett magas napállásnál mért nagyobb értékeket kiegyenlíti az alacsony napállásnál mért ellenkező

előjelű különbség. Ezzel szemben az őszi időszakban, amikor egész nap a szárazföld felett mért értékek a magasabbak, a napi összes sugárzásban szignifikáns különbség lép fel.

Az albedó napi menetére vonatkozó vizsgálataink igazolták, hogy 30°-40°-nál magasabb napállás esetén az albedó nem függ a napmagasságtól. Alacsonyabb napállásnál az albedó napi menetében aszimmetriát figyeltünk meg. A vizsgált napok 90%-ában az ugyanolyan napmagasság mellett délelőtt és délután mért albedóértékek eltérnek, a különbség a napmagasság csökkenésével fokozódik. Nyári hónapokban délelőtt, októberben délután mértünk magasabb albedóértékeket, szeptemberben nem volt egyértelműen kimutatható tendecia.

Vizsgálataink szerint a Balaton átlagos albedója júniusban a legkisebb: 3-5%, ezt követően fokozatosan emelkedik.

1. Introduction

The accurate knowledge of the heat balance of the Lake Balaton is essential for the discussion of flora and fauna of the lake. Lake Balaton acts as the habitat of a number of species of animals and plants. Climatic attributes of the habitat is greatly influenced by radiative energy absorbed, reflected and transmitted by the water surface.

The most important constituent of heat balance is the electromagnetic radiation absorbed by water surface. One component of it is the direct radiation coming through the atmosphere without being scattered. The other component is the diffuse radiation which has been scattered by the gas molecules of the air and the aerosol particles in the atmosphere. The sum of the diffuse radiation and the vertical component of direct radiation is called global radiation. The ratio of the two components strongly depends on the solar elevation and the meteorological conditions even at the same place. By annual mean the scattered radiation composes 40-50 % of global radiation in Hungary (Weingartner 1964). Global radiaton incident to the water surface is partly absorbed and partly reflected. The amount of energy absorbed and relevant to the heat balance can not be measured directly, however it can be calculated as the difference of incident and reflected radiation. This is why the subjects of our investigation are the amount of radiation energy reflected by the surface and the incoming radiation as well as the albedo defined as the ratio of those.

Last measurements related to radiation properties of Lake Balaton were carried out in the early seventies (Weingartner 1964, Dávid 1973). According to Weingartner's results, the albedo of water surface does not depend on the solar elevation when it is higher than 30°- 40°. In his publication the mean albedo varies between 6-8% in summer (Weingartner, 1964). 10 years later Dávid detected mean albedo between 8-10% in the same season (Dávid, 1972). The lowest value was measured in July (Dávid, 1972), though the albedo of Lake Fertő was minimal in June (Dávid, 1970). The values of radiation and albedo were not examined as a function of exact values of solar elevation but as a function of time. Because of the ecliptic movement of the Sun, the results of different days are intricate to compare on this way.

Major (1982) examined the Fresnel reflection of ideal water surface separately in the case of direct and diffuse radiation. The albedo referred to the former decreases exponentially as a function of the solar elevation while the albedo referred to the latter is nearly constant. The albedo referred to the global radiation including both of them in different ratio is the weighted average of their albedos. The ratio of the direct and diffuse radiation varies as a function of solar elevation. In consequence the albedo referred to the global radiation has a peak at solar elevation of 5 degree. This is a theoretical value deduced from the Fresnel equations.

Previously the measurements of albedo concerning Lake Balaton were carried out with sensors mounted on columns based on the shore. The columns settled by the Balatoni Integrációs Kht are the first ones which are able to record the real radiation conditions above the lake, filtering out all interfering effects completely due to being settled 1000 m from the shore. We applied two of these columns sited to Keszthely Bay and near Siófok. The continuous observation is also a new feature of current investigation.

In last decades the technological progress has made much more exact measurements possible, furthermore the change of climatic attributes has made them necessary. We intended to accomplish this purpose by this paper.

2. Materials and methods

2.1. Radiation data

The technical bases of our investigation are two hydrometeorological columns settled to Lake Balaton into the lake-body situated far from the shore in 2007 as part of the Life Project of Lake Balaton Development Coordination Agency (Balatoni Integrációs Kht). One of them is settled near Siófok (latitude: 46°58,28'; longitude: 18°03,67'), the other one is in the Keszthely Bay, a few hundred meters from the mouth of the River Zala (latitude: 46°47,01'; longitude: 17°16,63'). Both of them are equipped with sensors measuring global radiation, reflex radiation, air temperature, relative humidity, wind direction and wind speed. The values measured by the sensors has been averaged on five minutes basis and they are sent to the central computer of the measuring circuit. The global radiation and the reflex radiation are measured with outstandingly precise Kipp & Zonen CMP3 pyranometer. The spectral range detected by this device is between 310 nm and 2800 nm. The series of data necessary to our investigation were made available for us by the Balatoni Integrációs Kht. This paper analyses the measurements related to the Keszthely Bay.

The measurements began on 3rd July, 2007. The columns are taken out of the water in winter to prevent ice damage. Accordingly data series are available from periods between 3 July 2007 and 21 November 2007, 7 May 2008 and 6 November 2008 as well as 26 May 2009 and 21 September 2009.

The Agrometeorological Station of Keszthely made their data series of global radiation available for us as well. These data has been measured on ten minutes basis. The database enlarged on this way makes it possible to carry out the comparative analysis of values measured above the water with those measured in the standard meteorological station of Keszthely. The station of Keszthely is the vital part of the measuring network of the Hungarian National Meteorological Service.

As we have no exact figures of cloudiness we classified the days of the period under survey as clear, partly clouded and fully clouded by using the measured radiation data. The cloudiness influences both the intensity of global radiation and the spectral combination of it. Therefore it is necessary to examine the mentioned classes separately. At first the fully cloudless days were examined. Those days were ranked into this group on which the course of global radiation had regular shape. There were sixty days like this in our database. The results presented hereafter were made on the basis of the cloudless days.

2.2 Preparation of data series

The values measured were forwarded by sensors with SI unit of measurement, time was measured in Unix time. Its epoch is 01.01.1972. 00:00:00. Time value given in Unix time indicates how many seconds had passed since midnight of 1 January 1972 until the given time excluding leap-seconds. Unix time passes evenly while the standard time needs to be corrected from time to time because of the irregular rotation of the Earth. 23 leap-seconds were inserted between 1 January 1972 and the beginning of the measuring in 2007, the twenty-fourth was inserted at midnight on 31 December 2008. It was taken into account at converting of time values.

Solar elevation and azimuth of the Sun were calculated from exact time values, latitude and longitude. Beside the astronomical formulae, the apparent displacement caused by refraction in the atmosphere was taken into account. So the solar coordinates represent the apparent position of the Sun in our database.

2.3. Time correction

Time values of data series measured in 2008 on the column placed in the Keszthely Bay were incorrect. Daily maximum of global radiation should be at the highest solar elevation in clear days. According to measurements this maximum occurred before culmination. The difference was the same every day, its exact value was calculated by regression analysis. A third-degree polynomial was fitted on values of global radiation measured at solar elevation higher than 30 degree. The exact time of maximum was determined from its derivative. Time of culmination was determined from the date and the geographical coordinates. Difference of this values was calculated for each day, then they were averaged. In compliance with it, time values of data series measured in 2008 on the column placed near Keszhely were increased with 921 seconds (15 minutes 21 seconds).

3. Results

3.1. Comparison of global radiation measured above the water and in the meteorological station

As the distance between the Agrometeorological Station of Keszthely and the sensors mounted on the column placed in the Keszthely Bay is not more than 4500m, significant difference in global radiation was not expected. Unexpectedly the next results have been found. Daily course of global radiation values measured in the two different places differ significantly (Fig. 1a and b). At low solar elevation the values measured above the shore were larger while at higher solar elevation they were smaller. Global radiation values measured in the two different places are nearly equal at solar elevation of 40 degree. In summer between 10 a.m. and 15 p.m. higher global radiation can be expected above the water than predicted from values measured above the shore (Fig. 1a). From early autumn when angle of culmination is under 45° the higher values are measured above the shore (Fig. 1b).

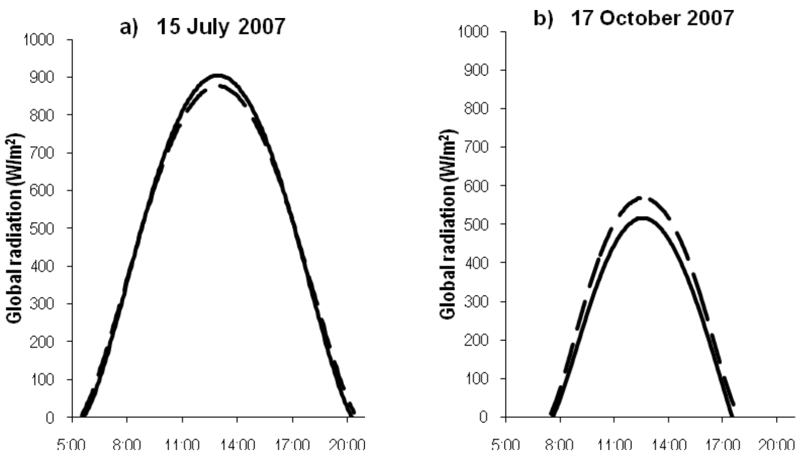


Figure 1: Global radiation measured above the water and above the shore as a function of time (UTC + 2h)

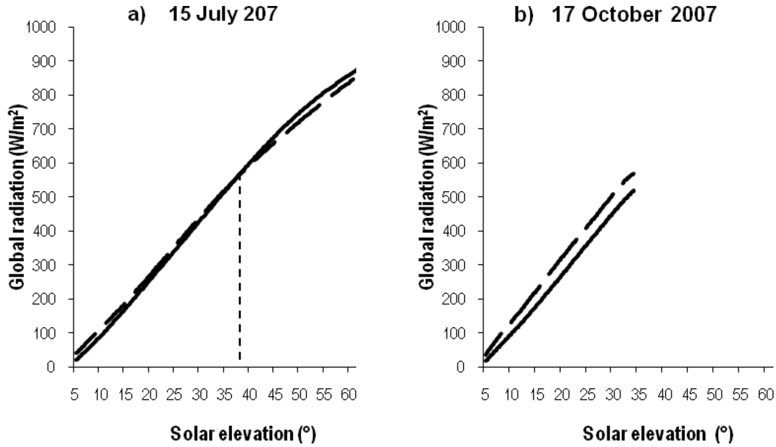


Figure 2. Global radiation measured above the water and above the shore as a function of elevation

Time values of the Fig. 1 are presented in standard time and daylight-saving time thus they are equal to UTC+2h. Values of global radiation are shown as a function of solar elevation in the Fig. 2. The chart of July (Fig. 2a) points out that global radiation values measured in the two different places are equal at 38 degree. Difference of daily peaks changes continuously, its trend is shown in Table 1, where exact values are listed from May to the beginning of November.

Table 1.

Peak of global radiation measured above the water and on the shore

	Peak above the water [W/m^2]	Peak in the shore [W/m^2]	Difference [W/m^2]
27 May 2008.	883	854	29
24 Jun 2008.	901	876	25
15 Jul 2007.	908	883	25
06 Aug 2008.	872	849	23
19 Aug 2008.	818	810	8
21 Sept 2007.	683	715	-32
15 Oct 2007.	540	592	-52
1 Nov 2007.	436	487	-51

From May to July peak values measured above the land are 2-4 percent (20-30 W/m^2) lower than those measured above the water. This relatively small difference is balanced by reverse difference measured at low solar elevation. Therefore significant difference is not found in the daily radiation sum calculated by integrating global radiation by time.

Table 2.

Daily total global radiation on clear days from May to November

	Total radiation above water [MJ/m^2]	Total radiation above shore [MJ/m^2]	Difference [MJ/m^2]
27 May 2008.	27.4	27.8	-0.4
24 Jun 2008.	27.6	27.7	-0.1
15 Jul 2007.	28.1	27.9	0.2
06 Aug 2008.	24.5	24.5	0
19 Aug 2008.	23.4	24.1	-0.7
21 Sept 2007.	17.0	18.3	-1.3
15 Oct 2007.	12.2	13.7	-1.5
1 Nov 2007.	8.5	9.3	-0.8

On the contrary, autumn peaks measured above the land are 5-12 percents (30-50 W/m^2) higher than those measured above the water. As the global radiation measured in the station is higher all day, there is a significant difference in the daily total radiation (Fig. 3, Table 2).

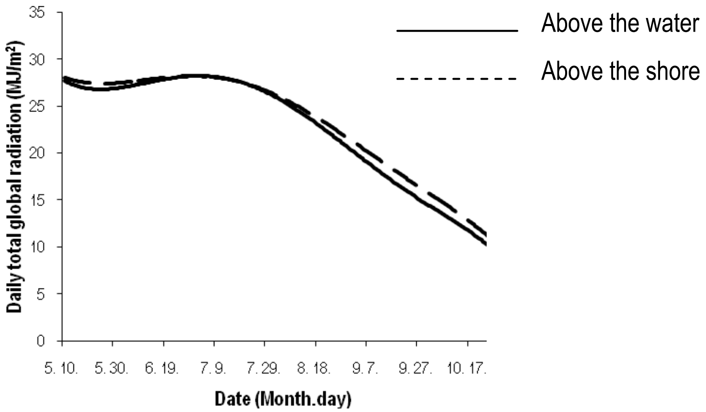


Figure 3.
Daily total global radiation measured above the water and above the shore

Theoretically the peak of total global radiation is expected to be on 22nd of July and formerly and thereafter it is expected to decrease almost symmetrically on the basis of insolation time (period between sunrise and sunset) and the angle of incidence of solar radiation. According to our investigation, the peak occurred in early July in 2007 and 2008, later than expected. It can be explained by features of the atmosphere. In the examined years, the sunny but strongly vaporous days at the end of June were followed by quite dry, hot days at the beginnig of July. There is no way to consider this phenomenon general because of the shortness of the examined period.

3.2. Daily course of albedo

Daily variations of albedo calculated as ratio of reflex radiation to global radiation measured above the water were investigated. A symmetrical chart as a function of time with a peak at solar elevation of 5 degrees was expected on the basis of both calculated and measured values of references. According to the measurements carried out by Weingartner (1964) above Lake Balaton the albedo decreases exponentially at lower solar elevation than 30°- 40 degree, on the other hand it does not depend on the solar elevation at higher position of the Sun (Weingartner, 1964). Latter statement is verified by our results. Deviation was found at low solar elevation. The chart of albedo was not symmetric on 90 percents of examined days, that is the values measured in the morning and in the afternoon at the same solar elevation were different (Fig. 4).

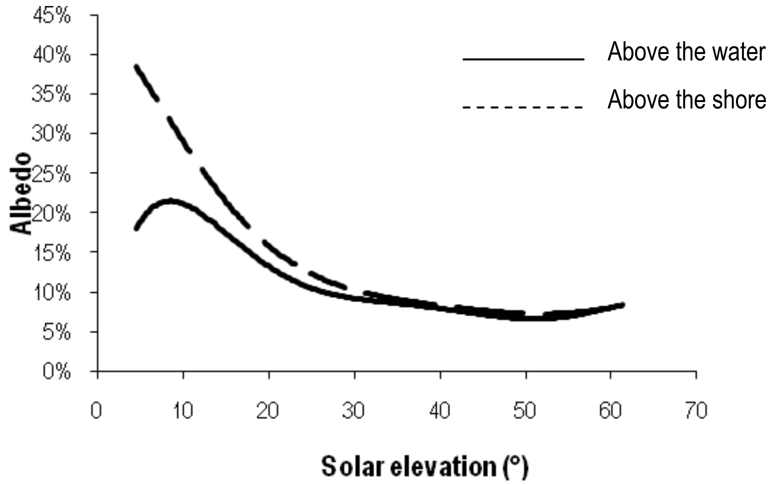


Figure 4.
Difference of albedo at the same elevation in the morning and in the afternoon (1 Aug 2007)

The albedo measured in the afternoon was higher on 20 % of the days while on 70 % of them the albedo measured in the morning was higher. The difference of albedos measured in the morning and in the afternoon at the same solar elevation is a function of the solar elevation. It is the smallest above solar elevation of 35 degree, where it is between 0-0,5 %. When the position of the Sun is lower than that, it increases significantly with decrease of solar elevation. The differences are very different in this range.

In summertime until the middle of September the albedo measured in the morning is regularly higher than that measured in the afternoon (Table 3). However, from the middle of October the tendency is reverse, the values measured in the afternoon are higher.

Table 3.
Average of albedo values measured in the morning and in the afternoon from June 2007 to August 2007.

Solar elevation (°)	Albedo in the morning	Albedo in the afternoon
10	0.30	0.19
11	0.27	0.19
12	0.24	0.17
13	0.21	0.16
14	0.20	0.15
15	0.18	0.14
16	0.16	0.13
17	0.16	0.13
18	0.14	0.12
19	0.14	0.11
20	0.12	0.11

The peaks in the diurnal course of albedo were also examined. According to the references this peak is accepted at solar elevation about 5 degrees and its value is about 0,2 (Major, 1982). Albedo values measured below solar elevation of 5 degrees were not utilized because a tiny inaccuracy in the measurement may result in large relative error. In 50 percent of the examined days this peak was not found in the morning while in 15 percent of the days it was not found in the afternoon. This peak was probably below 5 degrees. It is notable that the peak in the morning was not detectable in summertime while the peak in the afternoon was not detectable in fall. It is in accordance with our former findings. The smaller ratio of diffuse radiation causes that the peak of albedo is at lower solar elevation. The series of peaks was only complete for summer afternoons. On the basis of these data the mean albedo peak in summer cloudless afternoons is 0,27 at solar elevation of 7,7 degrees on the average.

Mean albedo is defined as the ratio of daily sum of radiation reflected by the surface to the daily sum of incident global radiation. Mean albedo of Lake Balaton is 6-8 % according to the measurements of Weingartner (1964). Our results verify these values. Mean albedo of Lake Balaton in Keszthely Bay was 6.8% in the examined period.

3.3. Annual course of albedo

Trend of albedo was investigated in each months. We had investigatable data from 2007 between July and October, and from 2008 between May and August. The values of solar elevation measured in degree were rounded to integer, the records were classified on the basis of it. Monthly average of the values of albedo of each class were calculated. This procedure was executed with the data from both Keszthely and Siófok (Fig. 5a, b, c, d).

According to the previous measurements carried out above the lakeshore (Dávid, 1973, 1976) the albedo of the surface is minimal in July then it increases continuously to set-in of the winter (Dávid 1970; Anda and Varga 2007). In 2007, the albedo of June was the lowest according to our investigation. Thereafter it increased continuously until autumn. Measurements on Lake Fertő (Dávid, 1971) pointed out results like this previously (Dávid, 1970). As both of the columns are several kilometres from the area used by bathers, the shift of minimum of albedo to earlier can not be explained with dreggy, less transparent water caused by more intense leisure time activities in the water. The most probable causes of this phenomenon are microorganisms, algaes and other plant species appearing in summer and influencing the colour and transparency of water.

Similarly to daily mean albedo the monthly mean albedo was calculated as the ratio of monthly total reflected radiation to monthly total global radiation (Table 4).

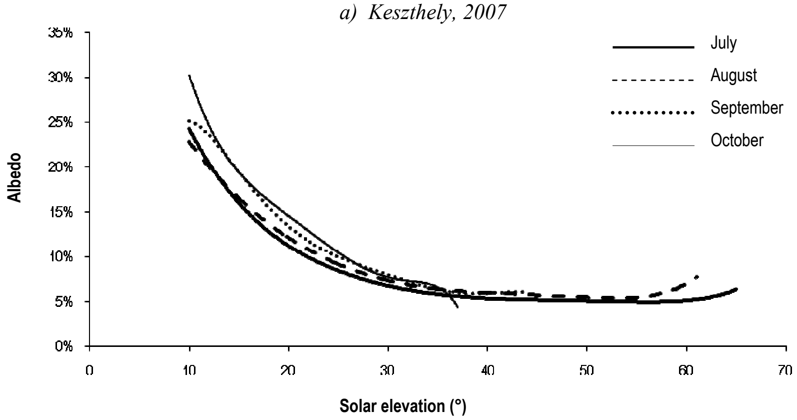
Table 4.

Monthly mean albedos for Keszthely bay and Siófok

	May	June	July	August	September	October
2007 Keszthely			6.2	6.7	8.1	9.7
2007 Siófok			3.8	4.7	7.0	9.5
2008 Keszthely	6.1	3.3	5.5	6.3		
2008 Siófok	5.5	4.3	6.3	6.4		

Striking difference can be observed in the albedos of Keszthely and Siófok during 2007. This difference was the highest in July (48%), later it decreased to 2%, the two kinds of values were nearly equal in October.

a) Keszthely, 2007



b) Siófok, 2007

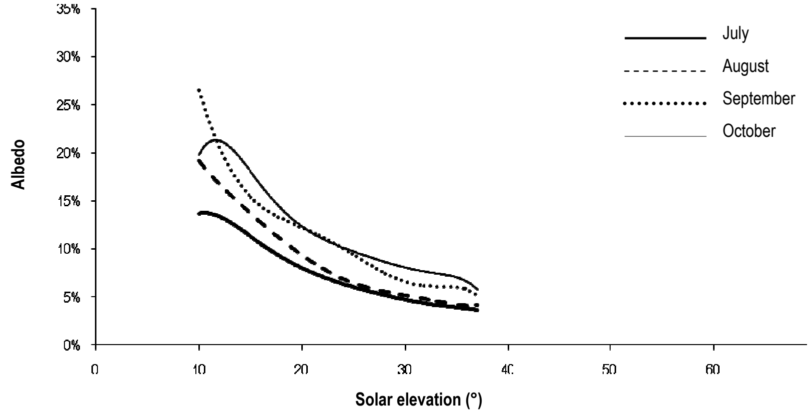
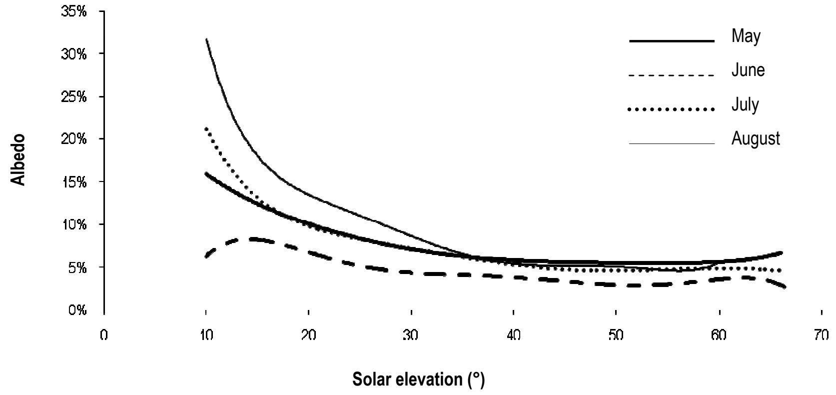


Figure 5 a,b: Monthly mean albedo as a function of elevation in 2007

c) Keszthely, 2008



d) Siófok, 2008

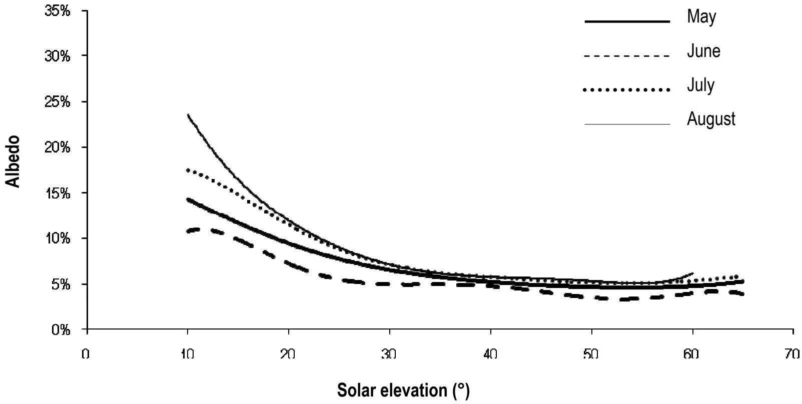


Figure 5 c,d: Monthly mean albedo as a function of elevation in 2008

The higher albedo of Keszthely Bay in comparision to Siófok was observed by Anda and Varga (2007) too. The sensors at Keszthely are settled about 1000 m distance from the mouth of the River Zala. So the difference can be explained with the impact of organic and inorganic matters coming from the river to the lake (black coloured humin acid). The characteristics of Keszthely Bay were already pointed out by Anda and Varga (2004).

4. Discussion

Significant difference is found between the global radiation measured above the water and in the shore at the same time. Previous measurements carried out above the Lake Balaton did not examine this aspect. The difference can not be explained with terrestrial long-wave radiation and the radiation of the atmosphere because their wavelength are larger than 3 μm while the upper limit of the pyranometers' spectral range we used is 2,8 μm. Difference found in daily peak of global radiation and alike in daily total of it results in difference in UV radiation.

This difference could be taken into account making medical weather forecast. These predictions are calculated from values of global radiation measured above the shore. However, this investigation points out that in summer just in the solar noon involving the largest UV-risk the difference is considerable.

In our study the mean albedo of the Lake Balaton is 6-8 %, which completely accords with earlier findings. It proves from a new aspect that the amount of components influencing both albedo and water quality did not change considerably.

Deviation of daily course of albedo from that expected on the basis of previous measuring was found at low solar elevation. Decrease of albedo with decrease of solar elevation under solar elevation of 10° was established by Dávid (1976) and Dávid and Kozma (1976). In addition two further results were observed. In Keszthely Bay in summertime the albedo measured in the morning is regularly higher than that measured in the afternoon at the same solar elevation. However, from the middle of October the values measured in the afternoon are higher. These results may be interpreted with the change in diffuse-to-direct ratio. At low solar elevation the albedo of the direct radiation increases with decrease of solar elevation angle, while the albedo of diffuse radiation is nearly constant. For this reason the diffuse-to-direct ratio affects the albedo to a large extent. During the daytime the amount of the precipitable water in the atmosphere increases and it causes the ratio of the diffuse radiation increases as well. That is why the albedo is lower in the afternoon. In the autumn days this effect becomes weaker and it is replaced by a stronger effect, the morning mist formation. These small waterdrops scatter considerably the solar radiation. Thus, the ratio of the diffuse radiation is larger at the same solar elevation in the morning than in the afternoon and so does the albedo. To sum it up, in summer afternoon the Rayleigh scattering caused by the water molecules while in autumn morning the Mie scattering caused by the water droplets result in lower albedo.

These effects result in the second finding, that is the higher the diffuse-to-direct ratio the higher solar elevation the peak of albedo is at. Asymmetry in the diurnal course of the surface albedo were found by Song (1998) and Mayor et al. (1997).

Investigating annual course of albedo significant difference was found between the values measured by Siófok and in the Keszthely Bay. Distance of the two columns is 62km, waterdepth is 3.3m at both of them and there was no significant difference in radiation attributes on examined days (same cloudiness). The albedo of the water surface was distinctly greater in Keszthely Ba10 y in 2007 and in May, 2008, while it was greater near Siófok in the summer of 2008. This period of two years is too brief to draw considerable conclusions from these data but points out that surface of Lake Balaton is not an uniform watersurface from the aspect of albedo.

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