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Calculating Irradiance Penetration into Water Bodies from the Measured Beam Attenuation Coefficient, II : Application of the Improved Model to Different Types of Lakes

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The method suggested earlier for estimating the spectra of diffuse attenuation coefficient of light in the water bodies relying on the beam attenuation coefficient measured from water samples, was improved and applied to different types of lakes. Measurement data obtained in 1994-95 and 1997-98 for 18 Estonian and Finnish lakes were used. The spectra of two characteristics were available for our investigations: 1) beam attenuation coefficient estimated from water samples in the laboratory with a spectrophotometer Hitachi U1000; 2) vertical irradiance (diffuse) attenuation coefficient measured *in situ* with an underwater spectroradiometer LI 1800UW. A total of 70 spectra were considered. Relying on these data the parameters of our earlier model were changed. The criterion of the efficiency of the new version of our model is the coincidence of the spectra of diffuse attenuation coefficient derived from Hitachi U1000 data (K_{dc}) with those obtained by underwater irradiance measurements (K_{dm}). Correlation analysis of the model's results gave the relationship K_{dm}=1.0023K_{dc} with correlation coefficient 0.961. The respective values of mean relative difference and standard deviation were 5.4% and 0.55 m^{-1}. This method may be useful in conditions where *in situ* measuring of underwater irradiance spectra cannot be performed because of weather conditions. As the measurement of the underwater radiation field is often a complicated and expensive procedure, our numerical method may be useful for estimating the underwater light climate.

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Introduction

As is generally known, the vertical irradiance attenuation coefficient (diffuse attenuation coefficient) $K_{d,\lambda}$ is an important and widely used radiation characteristic. Using the $K_{d,\lambda}$ values the downwelling irradiance $E_{d,\lambda}$ may be calculated by the following formulae

$$E_{d,\lambda}(z) \equiv E_{d,\lambda}(-0)\exp\left(-\int_0^z K_{d,\lambda}(\xi)\,d\xi\right) \tag{1}$$

or

$$E_{d,\lambda}(z) \equiv E_{d,\lambda}(-0)\exp(-\bar{K}_{d,\lambda}z) \tag{2}$$

Here z is the depth in the water, λ is wavelength of light, $E_{d,\lambda}(-0)$ is the incident irradiance just below the water surface (after refraction), $\bar{K}_{d,\lambda}$ is the averaged by depth value, and ζ is a depth between 0 and z. $\bar{K}_{d,\lambda}$ enables us to determine also the attenuation depth (important for remote sensing investigations) and euphotic depth.

$K_{d,\lambda}$ is an apparent optical property of the aquatic environment, which depends not only on the water properties, but also on the illumination conditions (solar zenith angle, cloudiness, angular distribution of radiation). Experimental determination of $K_{d,\lambda}$ is possible only by radiation measurements *in situ*, which, however, may be precluded because of weather conditions. On the other hand there exists an inherent optical property, the beam attenuation coefficient, c_λ, which can be estimated easily from water samples using a spectrophotometer. It may be useful to investigate the relationship between $K_{d,\lambda}$ and c_λ with the purpose of developing an approximate method for its estimation. This method could permit the spectral and vertical distributions of downwelling irradiance in a water body to be computed by taking water samples for determining the spectra of c_λ and recording the incident irradiance.

In 1996 we started this kind of investigations and the preliminary results were published in 1997 (Arst *et al.* 1997). The initial data were the results of two cruises of RV Arnold Veimer in summers 1987 and 1989, consisting of a total of 40 c_λ spectra in the range 400-700 nm. These results were obtained and the corresponding $K_{d,\lambda}$ values were measured with a prototype of multifunctional double underwater spectrophotometer LIKI (Laesson *et al.* 1988).

As known, connections between c_λ and $K_{d,\lambda}$ are described by Kirk's (1984, 1989) formulae

$$K_{d,\lambda}(\text{avg}) = \frac{1}{\cos\Phi_0}\left((c_\lambda - b_\lambda)^2 + (0.425\cos\Phi_0 - 0.190)(c_\lambda - b_\lambda)b_\lambda\right)^{\frac{1}{2}} \tag{3}$$

for clear sky and

$$K_{d,\lambda}(\text{avg}) = 1.168\left((c_\lambda - b_\lambda)^2 + 0.162(c_\lambda - b_\lambda)b_\lambda\right)^{\frac{1}{2}} \tag{4}$$

for overcast conditions.

Here $K_{d,\lambda}$(avg) is the average value for the euphotic zone, b_λ is the scattering coefficient, Φ_0 is the angle of the photons in the direct solar beam to the vertical just below the water surface (after refraction). As seen, the values of the scattering coefficient b_λ are also needed. Relying on LIKI data the relationships between c_λ and b_λ were described by the following equation

$$b(580\text{nm}) = 0.8c(580\text{nm}) \quad (5)$$

and the spectrum of b_λ was calculated relying on b(580) using either a linear or power function of λ (Arst *et al.* 1997).

However, defining the ratio $b(580)/c(580)$ to be a constant value 0.8 is only an approximate result and valid for a limited number of water bodies. Taking into account also the results by Bukata *et al.* (1979) and Halturin *et al.* (1983) one may expect that it is a more or less satisfying approximation for waters where $0.8<c(580)<2.3$ m^{-1}. However, even in this range of c(580) there are waters drastically different in their constituents. If the amount of yellow substance in the water is large or water turbidity is high, then $b(580)/c(580)$ has to be, respectively, lower or higher than 0.8. Consequently, the model needs improvement with the purpose to develop a method of calculations for a wide range of water bodies, including the cases when there is a considerable contribution of yellow substance in the light attenuation in the water.

Equipment and Investigation Objects

We decided to develop a new variant of our model using measurements performed in 1994-95 and 1997-98 in 9 Estonian and 9 Finnish lakes. The spectra of two characteristics were available for our investigations: 1) beam attenuation coefficient estimated from water samples in the laboratory with a spectrophotometer Hitachi U1000, and 2) diffuse attenuation coefficient measured *in situ* with an underwater spectroradiometer LI 1800 UW.

The Hitachi U1000 is an economic commercial laboratory spectrophotometer allowing the estimate of the beam attenuation coefficient with some predictive error. Here it should be noted that the measurement of beam attenuation coefficient is a complicated task for any type of spectrophotometer. The definition of the beam attenuation coefficient requires that the instrumentation used to measure it reject all scattered light (the beam transmittance should contain no contribution from scattering), but in reality all transmissometers accept some portion of the small-angle forward scattered light. The measured transmittance then exceeds the theoretical value and the attenuation coefficient determined from the measured transmittance is less than the true value. Some estimations of the relationship between the real and measured values of c_i are presented by Zaneveld *et al.* (1992) and Bricaud *et al.* (1995). Given the detector acceptance angle (0.9°) in the Sea-Tech transmissometers, it was found that the difference between the actual and measured beam attenuation coefficients (c_λ-$c_{m,\lambda}$) is 4-10% of the total scattering coefficient for various volume scat-

tering functions, *i.e.*

$$c_\lambda = c_{m,\lambda} + 0.07(\pm 0.03) b_\lambda \tag{6}$$

The results from the Hitachi U1000 give us the difference between the attenuation coefficient of the water under investigation and that of distilled water. That is, for treating the water samples the value c^*_λ is obtained

$$c^*_\lambda = c_\lambda - Fb_\lambda - c_{d,\lambda} \tag{7}$$

where c_λ is the real beam attenuation coefficient, Fb_λ is the contribution of the small-angle forward scattering to the measured radiation, and $c_{d,\lambda}$ is the attenuation coefficient of distilled water (all in m^{-1}). Of course, the correction F for the Hitachi U1000 is not automatically equal to 0.07(±0.03). Unfortunately the Hitachi U1000 manual does not provide us the necessary technical data. By our estimations the detector acceptance angle for Hitachi U1000 exceeds that for Sea-Tech transmissometer. The correction F for the Hitachi U1000 was estimated by increasing step by step from the starting value of F=0.05, and comparing the final results of the new version of the model with the measured K_d values. The corresponding data are shown in the next section.

The spectra of diffuse attenuation coefficient $K_{d,\lambda}$ were determined relying on the downwelling irradiance ($E_{d,\lambda}$) measurement data. The measuring instrument was an underwater spectroradiometer LI 1800UW. Its measuring range is 350-850 nm, but we used the data from 400 to 700 nm. The irradiance measurements were carried out starting at a depth of 0.5 m followed by each 0.5 m (sometimes the measurement interval was 1 m in deeper layers). In transparent lakes it was possible to determine 6-7 spectra at different depths, but in turbid lakes the number of the spectra was usually 3. For obtaining more stable results the measurements were carried out twice: first moving the device downwards and then lifting it upwards. The results were corrected taking into account the possible change of illumination conditions during the measurement procedure (for this the simultaneous recording of incident irradiance was performed with an integral radiation sensor LI 200 SA).

From the measured $E_{d,\lambda}$ the average values of $K_{d,\lambda}$ for the layers z_1-z_2 were computed as follows

$$\bar{K}_{d,\lambda}(z_2-z_1) = \frac{1}{z_1-z_2} \ln\left(\frac{E_{d,\lambda}(z_2)}{E_{d,\lambda}(z_1)}\right) \tag{8}$$

We denoted the diffuse attenuation coefficients determined in this way by K_{dm} (the wavelength index λ was omitted). These values were considered as the control values, comparing them with the values of K_d, obtained relying on c_λ by model calculations (denotion K_{dc}). Still, the values of K_{dm} possess various levels of accuracy. In case of *in situ* measurements there are some factors that cause instable or erroneous values of K_{dm}. Even if the errors due to quickly varying illumination are corrected, the phenomenon of underwater solar flashes, created in the surface layer by the in-

fluence of wind and undulation, causes fluctuations of the spectral curve of irradiance and corresponding errors in the values of K_{dm}. The accuracy of K_{dm} is low also in the case of very small values of irradiance: then both $E(z_2)$ and $E(z_1)$ may contain large relative errors and the value of $\ln [E(z_2)/E(z_1)]$ can also be erroneous. The latter effect is important in very turbid lakes and also at wavelengths 400-420 nm if the amount of yellow substance is large. Thus, the coincidence of K_{dc} and K_{dm} is definitely a good sign, but their noncoincidence (especially in conditions of high absorption) cannot describe the exact value of the error in K_{dc}. Despite these sources of variance, it is worth investigating whether we can reach a good coincidence between K_{dm} and the values of K_{dc}, estimated by our model.

For comparing these values we used the data collected from 9 Estonian and 9 Finnish lakes (Table 1). Note that the number of measurement series presented in

Table 1 – Some information on the lakes under investigation: z_D is the Secchi disk depth in m, C_{chl} is the concentration of chlorophyll *a* in mg/m^3, $C_{y,e}$ is the effective concentration of yellow substance in mg/L, n_L is the number of measurements of the diffuse attenuation coefficient.

Lake	area (km^2)	average depth (m)	z_D	C_{chl}	$C_{y,e}$	n_L
			Estonian lakes			
Arbi	0.045	(3)	1.6-1.8	6.6-17.3	6.8-8.8	2
Koorküla Valgjärv	0.441	8.5	2.9-4.8	2.3-11.5	2.7-10.7	1
Kurtna Nõmmjärv	0.156	3.1	2.5-4.5	0.7-3.3	4.0-14.1	2
Nohipalu Valgjärv	0.063	5.4	3.5-6.7	1.2-30	2.6-8.0	5
Paukjärv	0.086	5.9	4.8-6.5	4.2-7.9	1.2-7.7	2
Uljaste	0.60	2.2	1.0-3.4	3.1-45.8	8.8-18.4	2
Verevi	0.126	3.6	1.5-3.8	4.4-28.4	8.1-13.8	5
Võrtsjärv	270	2.8	0.15-1.0	25-102	9.7-16.4	4
Ülemiste	9.6	2.5	0.5-1.75	29-121	6-30	3
			Finnish lakes			
Enäjärvi	5.0	3.5	1.0	39.2	5.2	1
Kerävänjärvi	1.0	(1.5)	1.2	13.8	33.3	1
Lammi Pääjärvi	13.4	14.4	1.6-3.0	3.3-11.1	14.6-25.2	8
Lohjanjärvi	94	13.0	0.7-1.75	8.5-64.5	9.8-15.8	11
Puujärvi	6.5	(8.5)	3.0-6.0	3.6-6.1	3.8-5.5	2
Päijänne	70.3	15.0	3.5-5.9	1.3-1.7	7.5-9.6	4
Tuusulanjärvi	6.1	3.1	0.3-0.9	7.8-67	10.8-30.6	3
Valkeakotinen	0.036	3.0	0.8-1.1	7.8-8.4	26.2-32.7	2
Vesijärvi	112	6.6	1.2-3.7	1.7-26	3.6-7.1	12

Table 1 corresponds to the number used for the comparison of K_{dm} and K_{dc} (70 spectra). The amount of spectra is limited by difficulties in K_{dm} measurements (in some cases there were highly variable illumination conditions and strong fluctuations of E_d down to 2-2.5 m) leading to inaccurate results. For this reason we sometimes compared the spectra obtained not at 0.5 m, but in deeper layers. The parameters z_D, C_{chl}, and $C_{y,e}$ were measured considerably more often (for some lakes since 1992) including the year 1996 when LI 1800UW measurements were not performed. $C_{y,e}$ in Table 1 is the effective concentration of the yellow substance, estimated by the following equation (Højerslev 1980; Baker and Smith 1982)

$$a_{y,\lambda} = 0.565 C_{y,e} \exp\left(-S(\lambda-380)\right) \tag{9}$$

where $a_{y,\lambda}$ is the absorption coefficient of yellow substance, 0.565 is its average specific absorption at the wavelength 380 nm and S=0.017 nm^{-1}.

The bio-optical parameters of lakes under investigation show great differences (Table 1), the lakes varying from the oligotrophic lakes Paukjärv and Päijänne, to hypertrophic and dystrophic lakes such as Tuusulanjärvi and Valkeakotinen.

An Improved Model for Predicting $K_{dm,\lambda}$ Values from Laboratory Measurements of c_λ

The reference wavelength of our model is 580 nm (Arst *et al.* 1997). Thus, the first step is to find out how to determine the ratio A=b(580)/c(580), *i.e.* how large is the contribution of b to c at the wavelength 580 nm. The use of a constant value of A did not satisfy us, because this ratio depends on the relative amount of the water constituents and their optical properties. A rather important problem is how to take into account the influence of the yellow substance on the value of A. We tried to determine the algorithms, that lead to the best coincidence between the spectra of K_{dc} and K_{dm}. Of course, there are not only one but many variants that can be proposed: we tried three, which gave practically the same quality of results. In our model we have to remember also that the data of the Hitachi U1000 need correction. The algorithms chosen by us for determining the value of A and the method for the correction of the Hitachi results are described below.

The algorithms for determining the coefficient A are as follows

$$A = A_1 A_2 \tag{10}$$

$$A_1 = 1-\exp(-11A_1^*) \tag{11}$$

$$A_2 = 1-\exp(-A_2^*) \tag{12}$$

$$A_1^* \equiv \frac{2(c_0(400)-c_f(400))}{c_0(400)+c_f(400)} \tag{13}$$

$$A_2^* \equiv 1.1\left(c_0(580)\right)^{0.25} \tag{14}$$

Here $c_0(400)=c^*(400)+c_d(400)$, *i.e.* the value of $c_{m,\lambda}$ obtained from the Hitachi measurements for λ=400 nm, $c_0(580)$ is that for 580 nm and $c_f(400)$ is the result of the Hitachi for filtered water. The coefficient A_1* describes the relative difference between the measured beam attenuation coefficients of unfiltered and filtered water. As known, this difference is a good characteristic showing the influence of the yellow substance on the light attenuation. Applying Eqs. (10)-(14) to the lakes presented in Table 1 gave the variation of A in the range of 0.30-0.89. The low values of A (0.30-0.65) belong to the clear water lakes (Päijänne, Paukjärv, Puujärvi) as well as to brown-water Lake Lammi Pääjärvi (in this lake, due to a high content of yellow substance, absorption is comparable with scattering even at 580 nm).

As said above the Sea-Tech transmissometer correction cannot be automatically used, but its upper limit (0.1) seemed to be suitable for the Hitachi. The final values of $b(580)$ and $c(580)$ were found through an iteration of the equations

$$\begin{aligned} b_n(580) &= Ac_{n-1}(580) \\ c_n(580) &\equiv c_0(580) + 0.1b_n(580) \end{aligned} \qquad (15)$$

starting with n=1, and proceeding until n=10. After 5-7 steps the values of $c(580)$ and $b(580)$ were almost stabilised. The final result was

$$b(580) \equiv Ac(580) \qquad (16)$$

where $b(580)$ and $c(580)$ are corrected values of scattering and beam attenuation coefficients.

For describing the spectral distribution of the scattering coefficient we used the power law

$$b(\lambda) = b(580)\left(\frac{580}{\lambda}\right)^p \qquad (17)$$

where p=0.8. This value was chosen relying on the results of spectral distribution of scattering coefficient measured by the device *ac*-9 in 12 Finnish and Estonian lakes (Herlevi et al. 1999). Mostly they were the same lakes as investigated in the present work. The minimal value of p was 0.34, maximal 1.51, but most data were in the limits 0.52-1.24. We tested three values of p (0.6, 0.8 and 1.0) in our model, the best coincidence between K_{dc} and K_{dm} was obtained when p was 0.8. The correlation coefficient of this power function approximation usually exceeded 0.95, but the dataset was rather small (21 spectra, 9 points in each spectrum). Obviously, the spectral distribution of the scattering coefficient in different types of waters needs additional investigations.

Using the values of b_λ the corrected spectra of c_λ were determined by the following way

$$c_\lambda = c_{0,\lambda} + 0.1b_\lambda \qquad (18)$$

Relying on the spectra of c_λ and b_λ determined by our model the spectra of diffuse attenuation coefficient were calculated by Eq. (3) or (4). We cannot confirm that the

coefficient 0.1 in Eqs.(15) and (18) is the most truthful value for determining the corrected spectra of c_λ for Hitachi U1000. We were content with the value 0.1, because it allowed us to obtain satisfactory final results, the spectra of calculated diffuse attenuation coefficients, being close to the measured ones.

Application of the Model for the Estimation of the Spectra of Diffuse Attenuation Coefficient in Estonian and Finnish lakes

As said before, the only criterion of the model efficiency is the coincidence of the spectra derived from *Hitachi U*1000 data (K_{dc}) with those obtained by underwater measurements (K_{dm}). Some examples of this comparison are presented in Figs. 1-3. The lakes chosen for these figures are rather different in their transparency and content of optically active substances. As seen also in Table 1, lakes Päijänne and Paukjärv are clear-water, oligotrophic water bodies (Fig. 1), Lake Lammi Pääjärvi is characterized by a high amount of yellow substance (Fig. 2) and Lake Võrtsjärv is shallow and turbid (Fig. 3). As can be expected, the highest absolute differences between K_{dc} and K_{dm} occurred in case of Lake Võrtsjärv and also at wavelengths 400-420 nm in Lammi Pääjärvi. However, as discussed before, the reason can be not only the insuitability of the model, but also the measurement errors of K_{dm} in waters of very low transparency. Note that relative errors exceeding 30% are rare even for turbid Lake Võrtsjärv.

The other lakes showed approximately similar results, for some lakes (*e.g.* Lake Vesijärvi) all spectra coincided well, for some lakes (mostly turbid ones such as Tuusulanjärvi and Valkeakotinen) the coincidence was sometimes good, sometimes not. The correlation between K_{dc} and K_{dm} for all 13 wavelengths studied (Figs.1-3) and all lakes is shown in Fig. 4.

In this figure 70 spectra, each consisting of 13 points, were included. However, the total number of points in Fig. 4 is not 910 (as can be expected), but 885; the reason is that in some spectra the values of K_{dm} for 400 and 420 nm were missing . The correlation coefficient of Fig. 4 is 0.963 and the corresponding regression formula is

$$K_{dm} = 0.9515K_{dc} + 0.2048 \tag{19}$$

However, taking the intercept equal to zero we got the following regression formula

$$K_{dm} = 1.0023K_{dc} \tag{20}$$

in which case the correlation coefficient R=0.961. We calculated also the mean relative differences M_r and $|M_r|$ by the formulae

$$M_r \equiv \frac{1}{n} \sum_{i=1}^{n} \left(\frac{2(K_{dm}-K_{dc})}{(K_{dm}+K_{dc})} \right) \tag{21}$$

$$|M_r| = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{2|K_{dm}-K_{dc}|}{(K_{dm}-K_{dc})} \right) \tag{22}$$

and the standard deviation σ

$$\sigma = \left(\frac{1}{n}\sum_{i=1}^{n}(K_{dm}-K_{dc})^2\right)^{\frac{1}{2}} \quad (23)$$

where n is the number of measurements. The values of M_r, $|M_r|$ and σ are respectively 5.4%, 17.5% and 0.55 m^{-1}.

The values of M_r and $|M_r|$ are calculated also separately for each measurement wavelength to provide an indication of where, spectrally, the model is most accurate and most inaccurate. Additionally, the mean spectral absolute differences were calculated in following way

$$M_a = \frac{1}{n}\sum_{i=1}^{n}(K_{dm}-K_{dc}) \quad (24)$$

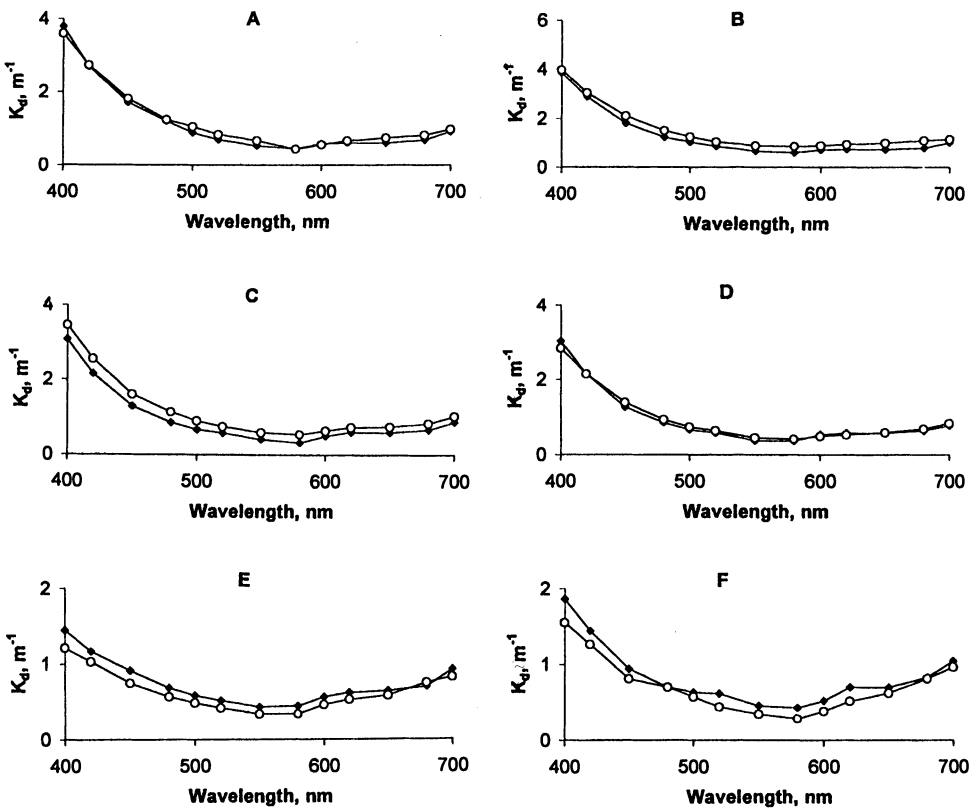

Fig. 1. Comparison of the spectra of diffuse attenuation coefficient K_{dc} (filled diamonds) with the corresponding spectra of K_{dm} (open circles) for Lake Päijänne: (a) June 1995, (b) August 1995, (c) May 1998, station 1, (d) May 1998, station 2, and for Lake Paukjärv: (e) June 1997, (f) August 1998.

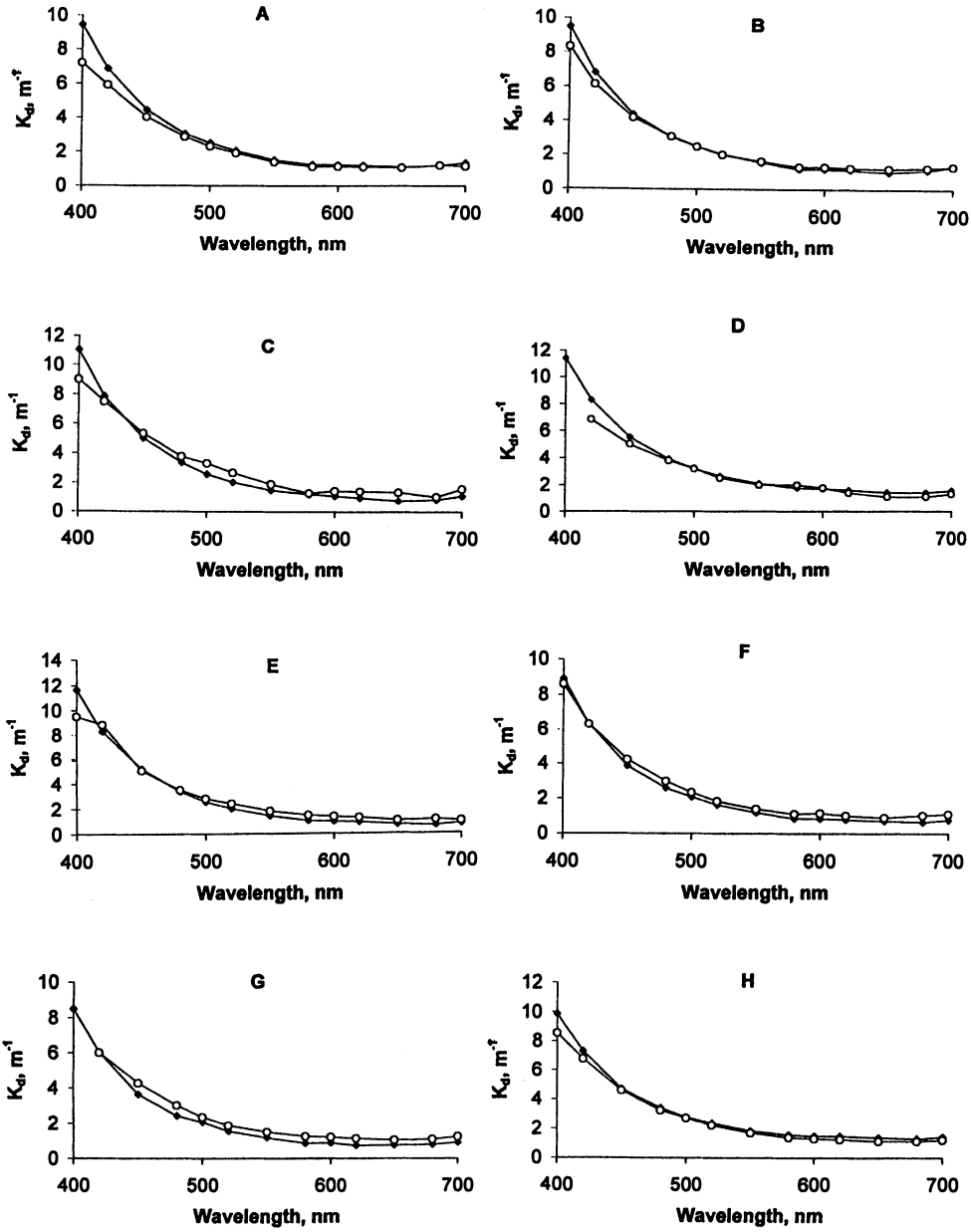

Fig. 2. Comparison of the spectra of K_{dc} (filled diamonds) with the corresponding spectra of K_{dm} (open circles) for Lake Lammi Pääjärvi: (a) August 1994, station 3, (b) August 1994, station 4, (c) May 1995, station 2, (d) May 1995, station 3, (e) May 1995, station 6, (f) August 1995, station 2, (g) August 1997, station 1, (h) May 1998, station 1.

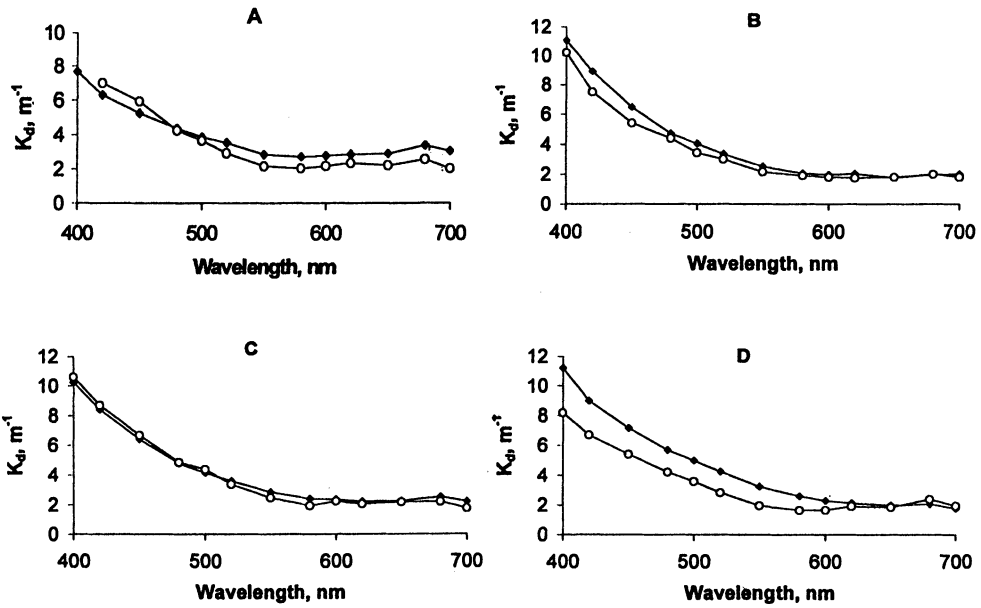

Fig. 3. Comparison of the spectra of K_{dc} (filled diamonds) with the corresponding spectra K_{dm} (open circles) for Lake Võrtsjärv: (a) September 1994, (b) June 1995, (c) August 1995, (d) August 1997.

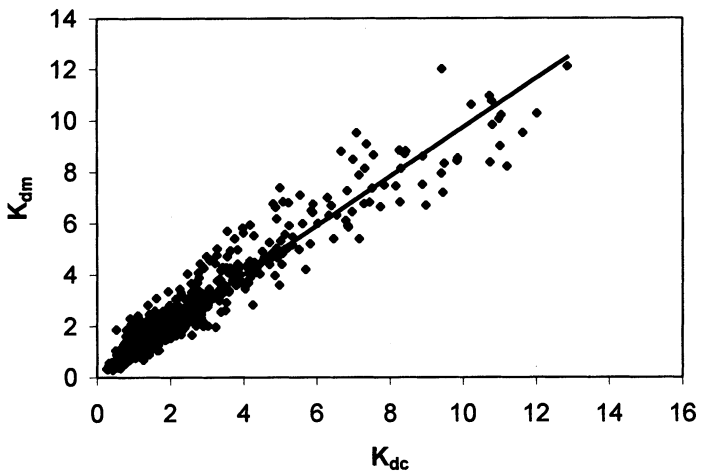

Fig. 4. Correlation between the values of the diffuse attenuation coefficient derived from the Hitachi U1000 measurements (K_{dc}) and those obtained from underwater irradiance measurements (K_{dm}). Data for 13 wavelengths between 400 and 700 nm for all lakes under investigation (Table 1) were used.

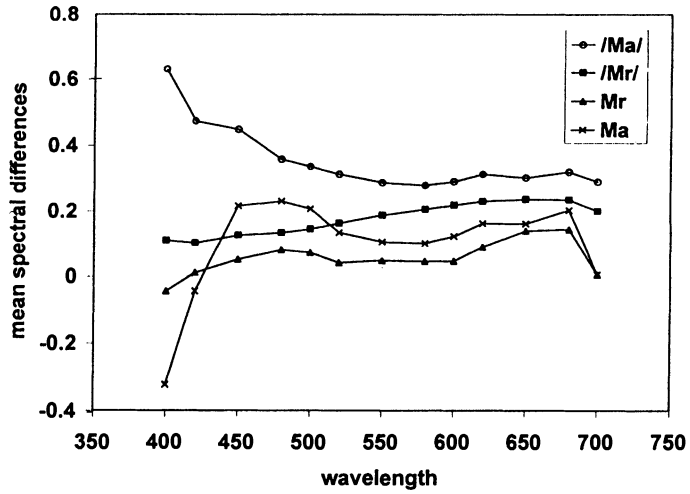

Fig. 5. Spectral distribution of the mean relative and absolute differences calculated by Eqs. (21), (22), (24) and (25).

and

$$|M_a| = \frac{1}{n} \sum_{i=1}^{n} |K_{dm}-K_{dc}| \qquad (25)$$

The results of the spectral distribution of relative and absolute differences (by Eqs. (21), (22), (24) and (25) are shown in Fig.5. As we can see, the values of $M_r(\lambda)$ are small (less than 5%) except for three wavelengths (620, 650 and 680 nm) when they are respectively 9%, 14% and 14.4%. The values of $|M_r(\lambda)|$ are around 10-16% in the region of 400-520 nm and, increasing with wavelength, obtain maximum value of 23.5% at 650 nm. The curves of $M_a(\lambda)$ and $|M_a(\lambda)|$ show extremely great absolute differences at 400 nm (at 420 nm and other wavelengths they are significantly smaller). Note, that all four curves decrease from 680 to 700 nm, $M_r(700)$ and $M_a(700)$ being equal to zero. We consider these results occasional. The main reason of higher values of the relative differences in 600-680 nm are small absolute values of K_{dc} and K_{dm} in this region. The slight maximum at 680 nm observed in the values of M_a, M_r and $|M_a|$ is hard to explain (connection with the absorption band of phytoplankton at 680 nm?). Data of Fig.5 allow estimation of the reliability of the model in different spectral regions, but the values of $M_r(\lambda)$, $M_a(\lambda)$,$|M_r(\lambda)|$ and $|M_a(\lambda)|$ are not identical to model's errors (as noted before, the values of K_{dm} have also some measurement error and the differences between K_{dc} and K_{dm} can be caused by errors of both characteristics).

This method has not been tested for very clear oceanic waters. We cannot declare that our method is perfect, giving always very good coincidence of K_{dc} and K_{dm}, but it seems to give satisfactory results for a wide range of lakes of different types.

Conclusions

The method for estimating the spectra of diffuse attenuation coefficient of light in water bodies relying on the beam attenuation coefficient spectra measured from water samples, was improved and applied to the different types of lakes. The numerical values of the coefficients in Eqs. (11),(14),(17) and (18) may depend to some extent on the fact that we used, for the measurements of c_λ, the spectrophotometer Hitachi U1000. But these coefficients are also a function of the concentrations and the types of optically active substances in the water, that allows modelling the connections between K_{dm} and K_{dc} for different water bodies. Our main conclusion is that in principle it is possible to build a model allowing rather accurate derivation of the values of spectral diffuse attenuation coefficient of light in the water bodies relying on the spectral beam attenuation coefficient measured from water samples in the laboratory.

Our method is indubitably of practical importance. It is helpful when measurements of the underwater irradiance *in situ* are impossible because of weather conditions. Monitoring of radiation by several underwater spectroradiometers in buoy-stations is technically complicated and rather expensive. To apply our numerical method, it is sufficient to take a number of water samples and to record the incident solar radiation. For estimating the variations of underwater light field in coastal regions and small lakes, the incident irradiance can be recorded at a station on the shore, whereas water samples are taken episodically from a vessel. Performing these measurements for an extended period of time will provide information on the underwater light climate of water bodies. Our method can be used also for predicting light penetration in a water body in which optical properties are changing in a known way (*e.g.* inflow of yellow substance in spring, lakes receiving industrial discharge).

In the present study the method was tested only for the lakes with a maximum Secchi disk transparency of about 7 m. We cannot claim it will work for very clear oceanic waters. Additional investigations are recommended also when using the model in case of strongly stratified waters and the model may be modified for very turbid waters characterized by high backscattering. Possibly, to minimize errors, it may be appropriate to first group the lakes according their dominant substance in the water and then obtain different algorithms for each group. This can be realized relying on large datasets for each type of water bodies.

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