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Optical properties and light climate in Lake Verevi

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Abstract

The optical properties and light climate during the ice-free period in the highly stratified Lake Verevi (Estonia) have been studied together with other lakes in same region since 1994. The upper water layer above the thermocline belongs to class "moderate" by optical classification of Estonian lakes but can turn "turbid" (concentration of chlorophyll *a* up to 73 mg m^{-3} and total suspended matter up to 13.2 g m^{-3}) during late summer blooms. In the blue part of the spectrum, light is mainly attenuated by dissolved organic matter and in red part notably scattering but also absorption by phytoplanktonic pigments effect the spectral distribution of underwater light. Consequently, the underwater light is of greenish-yellow color (550–650 nm). Rapid change in optical properties occurs with an increase of all optically active substances close to thermocline (2.5–6 m). Optical measurements are often hampered beneath this layer so that modeling of the depth distribution of the diffuse attenuation coefficient is an useful compliment to field measurements. $K_{d,PAR}$ ranges from 0.8 to 2.9 m^{-1} in the surface layer, and model results suggest that it may be up to 5.8 m^{-1} in the optically dense layer. This forms a barrier for light penetration into the hypolimnion.

Introduction

The amount of photosynthetically active radiation (PAR) in water bodies is important in many aspects of aquatic ecology. Light is the principal determinant of depth distribution of living organisms and photochemical processes (Kirk, 1994). The spectral compositions, amount and angular distribution of incident light, scattering and absorbing properties govern the light field in lakes.

Following Secchi depth, PAR is one of the easiest optical properties to measure in the light field. Optical properties describing attenuation and scattering of incident solar light with depth are diffuse attenuation coefficient, K_d and diffuse reflectance, R. They are a composite measure of the effect of suspended particles, phytoplankton pigments and yellow substance on the underwater PAR (Dera, 1992).

In this paper data and results from investigations of the optical properties and light field characteristics in Lake Verevi are summarized. From the optical point of view Lake Verevi is very interesting as there is a strong vertical gradient of optical properties between 2.5 and 6 m depths, depending on the season.

We present here the limits of observed concentrations of optically active substances (OAS) and optical properties. Also the spectral behavior of K_d and R are estimated and the optical characteristics of Lake Verevi are compared with other investigated lakes in the same region. The seasonal change of euphotic depth and percent of irradiance penetrating to water is calculated using modeled diffuse attenuation coefficients.

Material and methods

Measurements of OAS

The marine optics workgroup in the Estonian Marine Institute has visited Lake Verevi among other lakes in Estonia and Finland during the ice-free period of 1994–2001, on 19 occasions. Optical measurements were performed together with researchers from the Department of Geophysics, University of Helsinki. Water samples were taken from upper water layer ~20 cm below surface and 3–4 additional samples were taken from the deeper layers. In years 1994–1997, only surface water was sampled. Additional measurements of the concentrations of optically active substances (22 days, analyses from about 7 different depths) were collected by studies carried out by researchers from the Võrtsjärv Limnological Station of the Institute of Zoology and Botany in years 1999–2000 (Kangro et al., 2005; Nõges & Solovjova, 2005; Ott et al., 2005a).

The concentration of chlorophyll *a* (C_{chl}) was measured filtering the water samples through Whatman GF/F filters and applying a standard method based on measuring the absorption of chlorophyll dissolved in ethanol at the wavelength of 665 nm (ISO 10260, 1996). The concentration of suspended matter (C_s), was obtained by its dry weight after filtration of the water through pre-weighted Whatman GF/F filters. Amounts of optically active dissolved organic matter is expressed by the absorption coefficient $a_y(380)$ obtained from spectrophotometric measurements of filtered water (filters CF/C with pore size 0.45 μm) relative to a reference of distilled water. Attenuation coefficient, $c^*(\lambda)$, was determined from non-filtered samples of water using spectrophotometer Hitachi U1000, with distilled water as the reference. No correction for the small-angle forward scattering was applied. However, the previous analysis of lakes data show, that $c^*(\lambda)$ spectra are rather good indicators of water transparency and quality (Arst et al., 1996, 1999).

Irradiance measurements

Measurements of underwater downward irradiance in PAR region (400–700 nm) at different depths in water were carried out using a LI-192 SA (units μmol m^{-2} s^{-1}). The first measurement of irradiance was always made at 0.01 m, then after that at 0.3–0.5 m intervals down to the depth, where light could no longer be detected.

To determine the mean value of the diffuse attenuation coefficient over the PAR region and depth, $K_{d,PAR}$ was found as the slope of the regression line through a plot of logarithmic irradiance vs. depth. According to Bowling & Tyler (1985), this method can lead to considerable errors in very clear or strongly heterogeneous lakes. So in Lake Verevi, only the upper layer, where optically active substances are distributed relatively uniformly, was used for calculations of vertically averaged $K_{d,PAR}$.

Our measurement system enables to determine the values of $K_{d,PAR}$ also for separate water layers with a thickness of 0.5 m. Two LI-192 SA sensors were fixed on a frame at a distance of 0.5 m from each other. Lowering the frame with the sensors, the vertical profile of $K_{d,PAR}$ can be obtained on the basis of its values for 0.5 m thick layers. Using these simultaneously measured irradiances, the values of $K_{d,PAR}$ (Δ0.5) were calculated:

$$K_{d,PAR}(\Delta 0.5) = \frac{1}{0.5}\ln\left[\frac{E_{d,PAR}(z_1)}{E_{d,PAR}(z_2)}\right], \quad (1)$$

where, $E_{d,PAR}(z_1;\ z_2)$ are underwater downward irradiance values measured at depths z_1 and z_2.

The spectral distribution of underwater downward and upward irradiances were measured between the depths of 0.5 and 2–4 m at 0.5 m intervals. A spectroradiometer LI-COR, LI-1800 UW (measuring in the range 300–800 nm, with a resolution of 2 nm) was used. K_d was calculated by the same method as described above for $K_{d,PAR}$. The irradiance reflectance R is calculated as a ratio of upward irradiance (E_u) to downward irradiance (E_d):

$$R(z) = \frac{E_u(z)}{E_d(z)}. \quad (2)$$

Equation 2 is valid for all wavelengths (λ).

Model used for estimating K_d, from concentrations of OAS

During year 2000, Lake Verevi was sampled intensively but without any optical *in situ*