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Comparison of spectral irradiance measurements of the surface water layer in Lake Baikal with satellite data

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ABSTRACT. This work demonstrates the spectral measurements of underwater irradiance in the surface water layer of Lake Baikal. These measurements allowed us to obtain spectra of the vertical light attenuation coefficient, restore the spectral structure of the incident solar radiation, including changes of photosynthetically active radiation with depth, and calculate some primary bio-optical characteristics of water: spectra of the CDM absorption coefficient and the light backward scattering coefficient as well as the chlorophyll a concentration. We compare the results of measurements of underwater irradiance with the data obtained by the MODIS-Aqua/Terra colour scanners.

Keywords: Baikal, spectral irradiance, spectral attenuation coefficient, photosynthetically active radiation, in situ measurement.

1. Introduction

Experimental studies of the formation of the light field in Lake Baikal have a long history (Sherstiankin, 1975). With the implementation of new modern optical instruments for field research (Lee and Martynov, 2000; Lee et al., 2008; 2015), the acquisition of remote satellite data in the visible light spectrum and the development of regional bio-optical models (Suslin et al., 2018), researchers have significantly expanded the set of parameters responsible for the formation of the light field in the water. This work aims to demonstrate the possibility of obtaining some important bio-optical characteristics of the surface water layer by processing direct measurements of the spectral irradiance of natural light in the surface water layer of the lake.

2. Materials and methods

Spectral measurements of vertical irradiance and photosynthetically active radiation *(PAR*), as depth function, were obtained during the expedition onboard the research vessel "G.Yu. Vereshchagin", which was carried out at Lake Baikal from 24 July to 4 August 2018.

Measurements of the vertical distribution of horizontal irradiance in seven spectral channels (with the central wavelengths of 380, 443, 490, 510, 555, 590, and 620 nm) and *PAR*, as depth function, were carried out using the equipment developed at Marine Hydrophysical Institute of the Russian Academy of Sciences (Lee et al., 2015).

MODIS-Aqua/Terra Level-2 LAC data were used for generating spatial (4 km) and temporal composites, where noise was significantly reduced through averaging.

2.1. Method for restoring vertical light attenuation coefficient (K_d)

For each station, there were three variants to calculate the average K_d value for the following layers: 0–6 m, from 6 m to the maximum depth (z_{max}), and for the entire layer ($0 - z_{max}$). K_d was determined by the least squares method inside each of the three layers.

2.2. Calculating the thickness of the photosynthesis zone ($z(1\%PAR)$ and $z(0.1\%PAR)$) according to the K_d spectrum data

The $z(1\%PAR)$ and $z(0.1\%PAR)$ values were determined by the $\frac{PAR(z)}{PAR(0^-)}$ ratio.

2.3. Method for restoring inherent (*IOPs*) and apparent (*AOPs*) optical properties of water from K_d spectrum data

Values of chlorophyll concentration (C_a), light absorption by dead organic matter at a wavelength of

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490 nm (a_{CDM}(490)), backscattering by suspended matter at a wavelength of 555 nm (b_{bp}(555)), the spectral slope of backscattering coefficient by suspended matter (n_p), and the spectral slope of light absorption coefficient by dead organic matter (S) were determined through the minimum of a functional (Φ):

$$\Phi = \sum_{\lambda_1}^{\lambda_7} \left(K_d^m(\lambda, z) - K_d^i(\lambda, z) \right)^2,$$

where $K_d = 1.2(a + b_b)$; $a = a_w + a_{CDM} + a_{ph}$; $b_b = b_{bw} + b_{bp}$; a_w, b_{bw} are the coefficients of absorption and backscattering by pure water (Smith and Baker, 1981; Pope and Fry, 1997); $a_{ph}(\lambda) = a^*_{ph}(\lambda) \cdot C_a$; a^*_{ph} is the specific absorption coefficient of phytoplankton, and C_a is chlorophyll *a* concentration (Bricaud et al., 1995).

2.4. *PAR* and the bio-optical properties of the upper layer of Lake Baikal waters according to satellite data

A table was compiled for Lake Baikal, which contains diurnal values of *PAR* incident on the surface during the day, as well as *IOPs*, *AOPs* and C_a. The used data array was based on the standard satellite product obtained by MODIS-Aqua/Terra colour scanner, which was specially processed (Suslin et al., 2015).

3. Results

According to the spectral measurements of horizontal irradiance, we obtained the values of the vertical attenuation coefficient, K_d, and restored average values of bio-optical characteristics: the light absorption coefficient by dead organic matter, a_{CDM}(490), chlorophyll concentration, C_a, and backscattering coefficient by suspended matter, b_{bp}(555).

The comparison (on the same day) of the standard satellite product (NASA, AQUA, 2018; NASA, TERRA, 2018; Frouin et al., 2003) with *in situ* measurements and model calculations by *IOPs* revealed the following results:

- the standard satellite product was obtained on the day of measurements only for one station (station 28) of 13 stations: *std* K_d(490) = 0.349 m^{-1} and C_a(*std*) = 5.25 mg m^{-3};
- both standard satellite products are overestimated relative to the direct *in situ* measurement K_d(490) = 0.132 m^{-1}, as well as to model estimate C_a(*IOPs model*) = 4.9 mg m^{-3}, in the layer of 0-6 m, which is the expected result for waters with a high content of dissolved organic matter relative to the open ocean waters.

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