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RELATIONSHIP OF BIO-OPTICAL CHARACTERISTICS OF LAKE TELETSKOYE AT DIFFERENT HORIZONS ACCORDING TO THE RESULTS OF AN EXPEDITION IN AUGUST 2023

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Abstract

To solve inverse problems, in particular, the recovery of optically active substances from hydro-optical measurements, it is necessary to clearly understand the nature of these dependencies. The work analyzes such relationships between the fluorescence of dissolved organic matter, chlorophyll-*a* fluorescence and the beam attenuation coefficient at a wavelength of 660 nm based on direct measurements performed in Lake Teletskoye in August 2023. It is shown that the waters of Lake Teletskoye belong to the so-called waters of the second type (CASE2) according to the Morel classification, i. e. optically complex waters.

Keywords: Lake Teletskoye, profiles of water bio-optical parameters, beam attenuation coefficient, chlorophyll-*a* and dissolved organic matter fluorescence

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ВЗАИМОСВЯЗЬ БИООПТИЧЕСКИХ ХАРАКТЕРИСТИК ТЕЛЕЦКОГО ОЗЕРА НА РАЗНЫХ ГОРИЗОНТАХ ПО РЕЗУЛЬТАТАМ ЭКСПЕДИЦИИ В АВГУСТЕ 2023 ГОДА

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Аннотация

Для решения обратных задач, в частности, восстановления концентрации оптически активных веществ по гидрооптическим измерениям, необходимо использовать характер этих связей. В работе проведён анализ таких связей между флуоресценцией растворённого органического вещества, флуоресценцией хлорофилла-*а* и показателем ослабления направленного света на длине волны 660 нм на основе прямых гидрооптических измерений *in situ*, выполненных в ходе комплексной экспедиции на Телецком озере в августе 2023 года. Показано, что на разных глубинных горизонтах воды Телецкого озера относятся к так называемым водам второго типа (*CASE2*) по классификации Мореля, т. е. оптически сложным водам.

Ключевые слова: Телецкое озеро, профили биооптических параметров воды, показатель ослабления света, флуоресценция хлорофилла-*а* и растворенного органического вещества

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1. Introduction

Lake Teletskoye is the largest body of water in the Ob River basin. It is located in the northeastern part of the Altai Mountains at an altitude of 434 m above sea level and is part of the lake-river system of Eastern Altai[1]. The Secchi disk depth in summer reaches a maximum value [2] of 12–15 m. The average width of the lake is 2.9 km and the maximum is 5.2 km, the surface area is 227 km^2. Due to its great depth (average depth 181 m, maximum 323 m), it contains 41.1 km^3 of fresh water. According to its hydrothermal characteristics, the lake is dynamic with two periods of complete convective mixing to maximum depths due to the thermal bar (May-July and October-December) [3].

According to Selegey's phenomenological model [3] the period of summer heating of the lake ends in the second ten days of July. A common feature of summer conditions is that the lake is thermally stably stratified and reaches surface temperatures [4] above 10 °C. In the practice of assessing water quality, as well as the bioproductivity of water bodies, Secchi disk depth was used. Secchi disk depth depends on the content of mineral and organic suspended matter and dissolved organic matter in the water. Thus, this hydro-optical parameter contains information about the content of substances in water that are indicators of the ecological state of the reservoir [5, 6].

To solve the problem of restoring the concentration of optically active components from the measured optical parameters of water, it is necessary to have an idea of the nature of these relations. For this purpose, three key bio-optical parameters of the aquatic environment were selected. The first is the fluorescence spectrum of colored dissolved organic matter (*fDOM*), the concentration of which affects the absorption of light in the spectrum short-wave part. The second parameter is the beam attenuation coefficient at a wavelength of 660 nm (*Turb*), which is associated with the concentration of suspended particles (phytoplankton, mineral suspended matter and detritus) contained in the water. The third parameter is the fluorescence spectrum of chlorophyll-*a* (*fChla*) associated with phytoplankton, which contributes to both the total light absorption and light scattering [7].

The purpose of this work is to investigate the features of the relationships between key bio-optical characteristics in the upper hundred-meter layer of the lake, associated with the concentration of optically active absorbing and scattering substances, both living and non-living components.

2. Materials and Methods

The work analyzes field data obtained quasi-synchronously using hydro-optical sounding equipment, including a multichannel fluorimeter [8], developed in the department of Optics and Marine Biophysics of the Marine Hydrophysical Institute of RAS, and the hydrophysical complex "CONDOR"[9].

Vertical profiles of temperature (*T*) and beam attenuation coefficient at 660 nm (*BAC* or *Turb*) were obtained by the "CONDOR" complex. The submersible autonomous complex "CONDOR" performed synchronous measurements of temperature (*T*), beam attenuation coefficient (*BAC* or *Turb*) at 660 nm, calibrated in turbidity units. Technical characteristics and detailed instrument description are given in [9]. *BAC* in the red part of the spectrum is determined by the scattering properties of the total suspended matter and does not depend on the absorption of the colored component of the dissolved organic matter [10]. *BAC* calibration was carried out in laboratory conditions before the expedition based on the results of measurements of formazin suspension solutions with a given concentration (ftu units). According to [11], beam attenuation meters can be calibrated in both ftu and m^{-1}. The temperature measurement range was from –2 to 35 °C with an accuracy of 0.04 °C, and the *BAC* measurement range was from 0.2 to 10 ftu with a resolution of 0.01 ftu.

The multichannel fluorimeter performed quasi-synchronous measurements of the fluorescence profiles of dissolved organic matter (*fDOM*) (excitation wavelength 360 nm, recording wavelength 570 nm) and chlorophyll-*a* (*fChla*) (excitation wavelength 460 nm, recording wavelength 678 nm).

The range of measured values of *fChla* is from 0.05 to 45 μg/L. Intercalibration of measurements with the Turner Design Chl-a sensor was carried out using synchronous measurements of vertical profiles. The data correlation coefficient was $r = 0.93$ with a statistical significance coefficient of $p < 0.05$. No such work has been done for *fDOM*. *fDOM* data are presented in relative units and are indicative, i. e. they show qualitative changes, not quantitative ones.

The measurements were carried out on board the ship-laboratory of the Institute for Water and Environmental Problems, Siberian Branch of RAS.

Figure 1 shows a map of 11 stations at which synchronous measurements were made with a multichannel fluorimeter and the "CONDOR" complex.

Table 1 provides a list of stations where synchronous measurements were performed using a multichannel fluorimeter and a "CONDOR" complex. The total number of synchronous stations is 11. The maximum depth to which synchronous measurements were carried out by both instruments was about 150 m. The average value of the upper mixed layer (UML) for these stations is 7 m. The UML was calculated based on the condition of a temperature drop of 2 °C from its value on the surface. The average value of the euphotic zone depth (Z_{eu}) was 13 m.

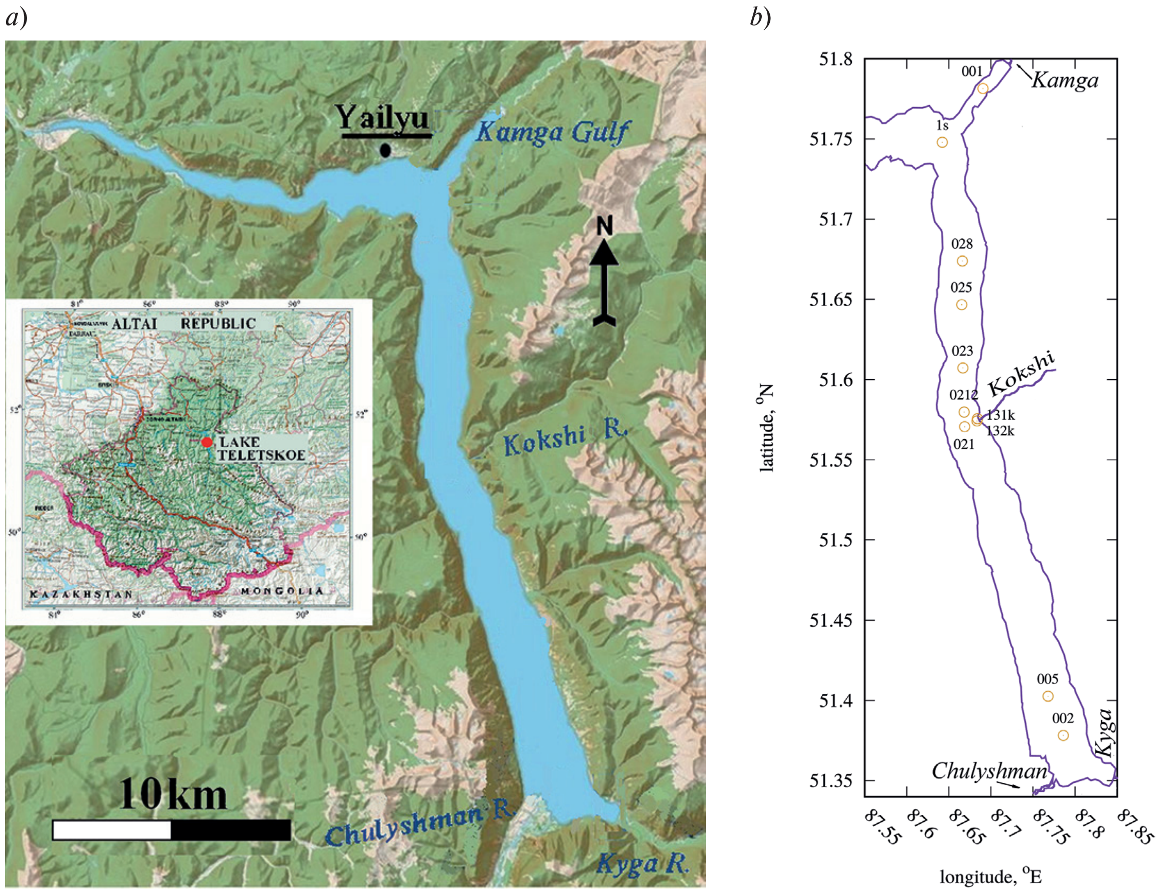

Fig. 1. Map of Lake Teletskoye (*a*) and station's (*b*) locations at which synchronous measurements were performed with a multichannel fluorimeter and the "CONDOR" complex

Table 1

List of stations where synchronous measurements were performed using the multichannel fluorimeter and the "CONDOR" complex and some of their characteristics

N	Station symbol	Z_{UML}, m	Z_{EU}, m	Maximum probing depth, m
1	001	7	14.0	22.6
2	005	14	12.2	41
3*	131k	20.6	12.6	21
4*	002	5	13.0	50.2
5	132k	10	13.0	20.2
6	021	5.2	9.2	24.8
7*	0212	3	13.4	148
8	023	3.4	15.0	34.8
9*	025	5.6	16.2	43.6
10	028	4.8	15.2	47.4
11	1s	8	14.8	47.4

* the profiles of the measured characteristics of the lake water column for these stations are shown in Fig. 2 and 3.

In Fig. 2 and Fig. 3 shown examples of measurements of profiles *Turb* (Fig. 2a, Fig. 3a), *T* (Fig. 2b, Fig. 3b) with the "CONDOR" complex and profiles *fDOM* (Fig. 2c, Fig. 3c) and *fChla* (Fig. 2d, Fig. 3d) with the multichannel fluorimeter at stations 131k, 025 and 002. These examples show the characteristic scales of variability of bio-optical parameters with depth in the estuary area of the station 131k, at station 025 in the northern deep-water part of the lake which slightly exposed to river flow, and in the southern part of the lake on station 002, which is influenced by the main Chulyshman river flow to the lake.

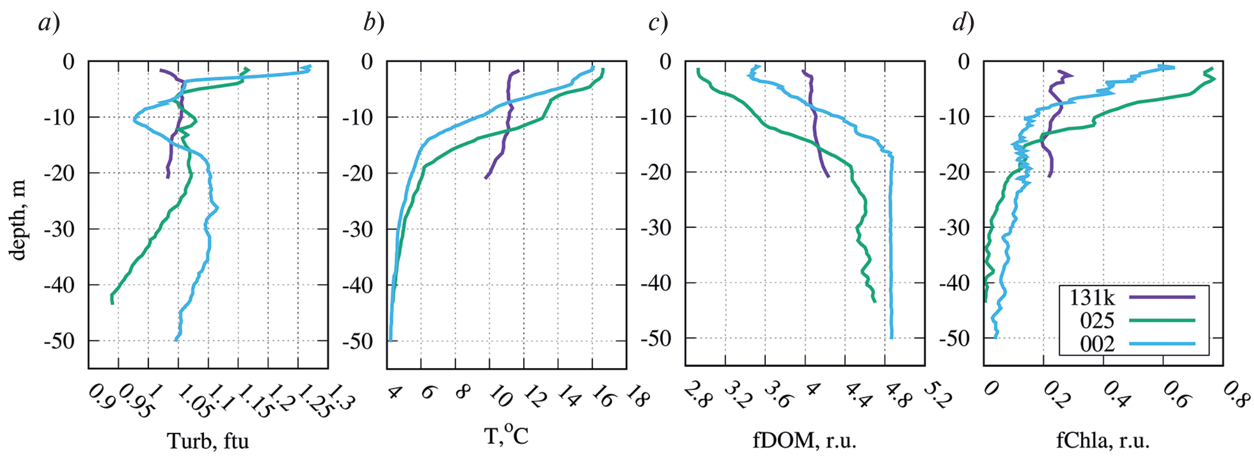

Fig. 2. Examples of measured profiles *Turb* (a), *T* (b), *fDOM* (c) and *fChla* (d) at stations 131k, 025 and 002

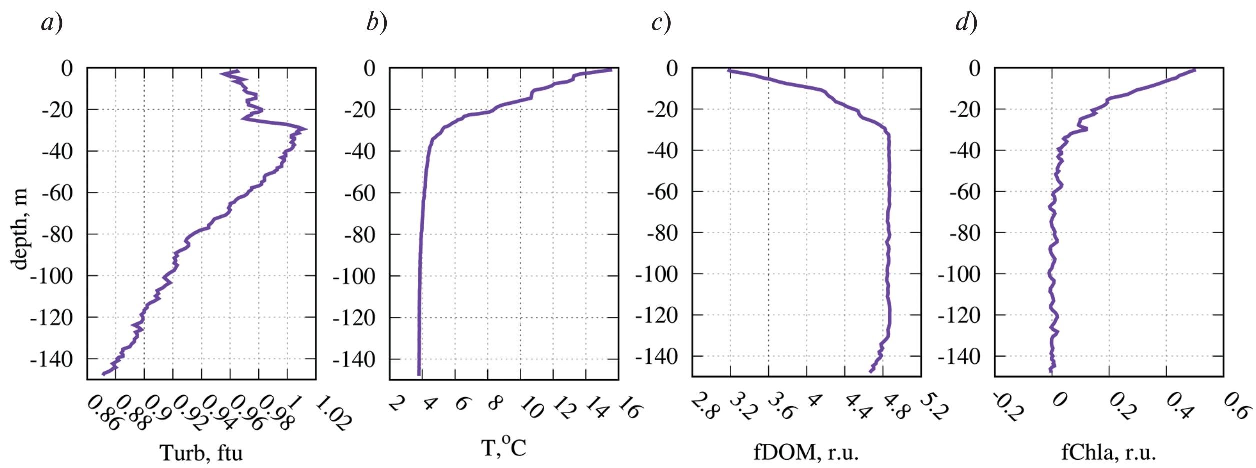

Fig. 3. Examples of measured profiles *Turb* (*a*), *T* (*b*), *fDOM* (c) and *fChla* (d) at station 0212

Noteworthy is the different behavior of *Turb* in the upper water layer of the lake at station 131k and station 002. Both stations are located in the estuary areas, but at station 002 the value of *Turb* is significantly greater than at station 131k, which indicates a higher level of entering of suspended material from the river Chulyshman mouth. The *fDOM* values in this layer for these stations have the opposite nature, which indicates a low content of dissolved organic matter in the river Chulyshman compared to the waters of the lake.

4. Results and discussion

The results of synchronous measurements for all stations are presented in Fig. 4.

They show the relationship between bio-optical characteristics in Lake Teletskoye in August 2023: *Turb* and *fDOM* (Fig. 4a); *Turb* and *fChla* (Fig. 4b); *fChla* and *fDOM* (Fig. 4c). Figure 4d demonstrates the relationship between *T* and *fDOM*. This was done to show the relationship between *fDOM* and density, and also the presence of a subsurface *fDOM* maximum, since namely temperature in the absence of salinity determines the density stratification of the lake.

Let us note the main features of the relationships between the considered bio-optical parameters of the lake water column (for depths of 0–150 m, in warm periods of year). The first is the lack of connection between *Turb* and *fDOM* (Fig. 4a), which is an indisputable fact that the waters of Lake Teletskoye belong to the Case 2 type [12]. The same applies to the connection between *Turb* and *fChla* (Fig. 4b) for the photosynthesis layer. Secondly, a negative correlation in the photosynthesis layer occurs for *fChla* and *fDOM* (Fig. 4c) and between *T* and *fDOM* (Fig. 4d), but it is "blurred", i. e. there is no one-to-one correspondence.

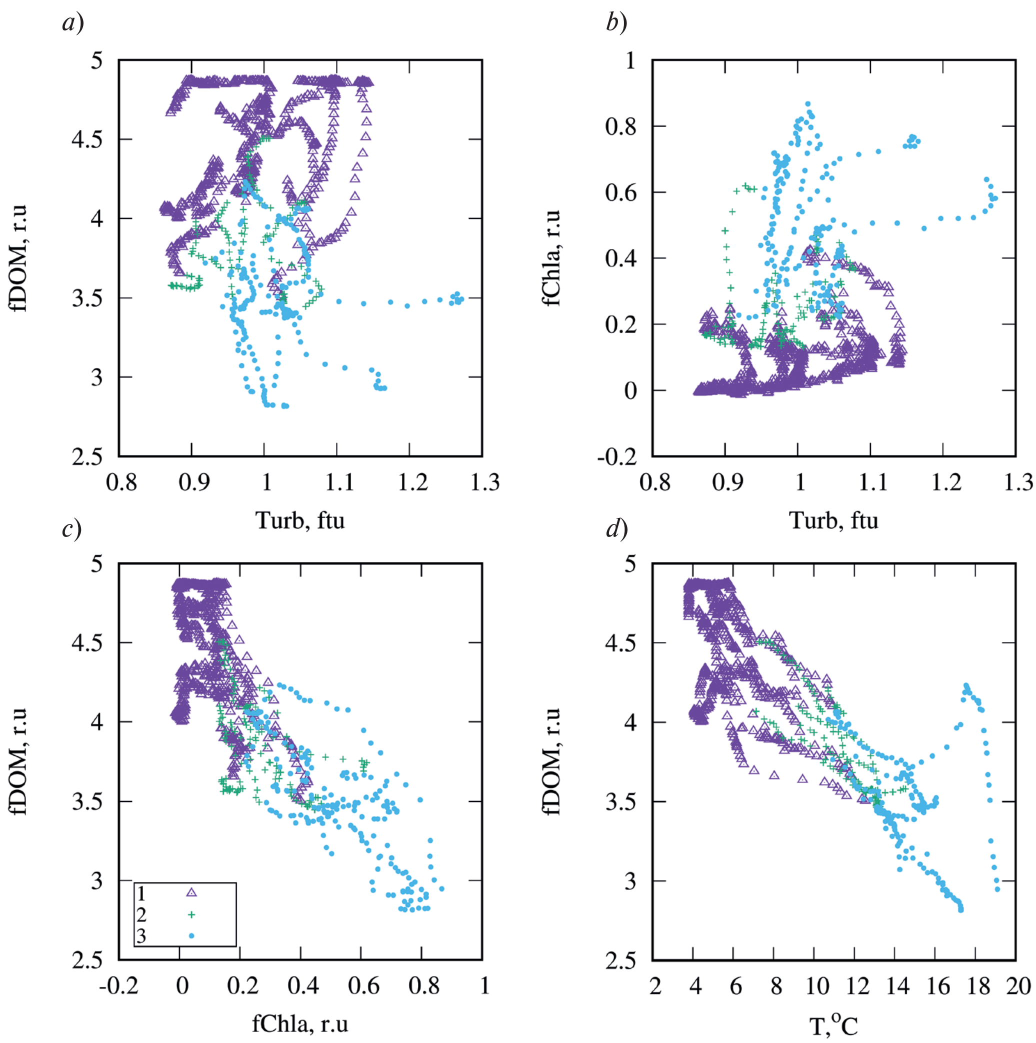

Fig. 4. Relationship between bio-optical characteristics in Lake Teletskoye in August 2023: *Turb* and *fDOM* (*a*); *Turb* and *fChla* (*b*); *fChla* and *fDOM* (*c*); *T* and *fDOM* (*d*), where *Turb* is the beam attenuation coefficient at 660 nm (in turbidity units); *fDOM* — fluorescence signal of colored dissolved organic matter in rel. units; *T* — water temperature in Centigrade (°C). Various horizons are shown by dots of different colors: 1 — below the average value of the photosynthesis layer (13 m); 2 — layer between the lower boundary of photosynthetic layer Z_{eu} and the average value of the lower boundary of the upper mixed layer (7 m); 3 — upper mixed layer (0–7)

5. Conclusions

The final conclusions can be formulated as follows:

– the absence of a relation between *Turb* and *fDOM* in the entire 150 m layer is an indisputable fact that the waters of Lake Teletskoye belong to the Case 2 type. The same statement is true for the connection between *Turb* and *fChla* in the photosynthesis layer;

– there is some negative correlation into the photosynthesis layer for *fChla* and *fDOM* and between *T* and *fDOM* in the entire 150 m layer.

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