Spectral transmittance of surface waters in the middle reaches of the River Ob

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Received November 15, 1999

The paper describes the results of measurements of spectral coefficients of light extinction in the surface layer of the River Ob water along the path from Tomsk to mouth of the River Irtysh. The values of decimal coefficients vary within the limits from 2.1 to 10.4 m^{-1} and exhibit marked spectral variations. The dominating yellow color of the water downstream the mouth of River Chaya is due to the inflow of the so called yellow substance from the marshes of the Western-Siberian lowland and the enhanced content of iron in the mineral particles. The role of large and small hydrosols in forming the total extinction coefficient is estimated.

The investigation of the processes of light propagation in natural waters has long been an integral part of the complex studies performed in the external water bodies – seas and oceans.[1–3] The vast observation material has been accumulated that allowed the development of the corresponding radiation models of objects. The inland water bodies – large lakes and reservoirs[4–7] were studied much less and the rivers and marshes were practically not investigated at all. Thus in modern literature we did not manage to find information on optical parameters of water in the above-mentioned ecosystems of the huge territory of the Western Siberia.

In connection with the above-said the research work has begun at Institute of Water and Ecological Problems, SB RAS and at the Altai State University on the investigation of the radiation regime in the water bodies of Western Siberia. As far as we know, the most important characteristic feature, determining the process of radiation transfer in turbid media, is the spectral transmission. To measure the spectral transmission, a special setup was installed consisting of a light source with the angle of the beam divergence of 3°, a vertically positioned cell with a transparent bottom and a lock of levels of water filling, a set of interference filters, a photodetector FEU–62, and a signal recorder. The thickness of a residual water layer, corresponding to "zero" level, was 3 mm. The diameter of a light spot at the cell exit did not exceed the photocathode size. The interference filters had the transmission band half-widths about 9 nm and peak values at 455, 495, 555, 598, 670, 707, and 801 nm. The validation of the results obtained using the setup was tested when performing the experiments with settled distilled water. The measurement data on the absorption coefficients were found to be in close agreement with the literature data.[2,5,7]

We accepted an offer of the International Research Center for Environmental Physics and Ecology of Tomsk Scientific Center, SB RAS and took part in the complex experiment "Poima–99" on the investigation of the ecological situation in the environment of the middle reaches of the River Ob, from Tomsk to the mouth of the River Irtysh. This paper describes the results on the extinction coefficients measured in samples of the near-surface water (on the average, from the depth of 15 cm).

Figure 1 shows typical measurement data on the values of common logarithm of the ratio of light fluxes measured at different levels of filling the cell with water, to the flux measured at zero-level filling, the so-called Bouguer straight lines. Each of them corresponds to the three-fold variation of the water column height in the cell. The experimental errors are shown at the confidence coefficient 0.95.

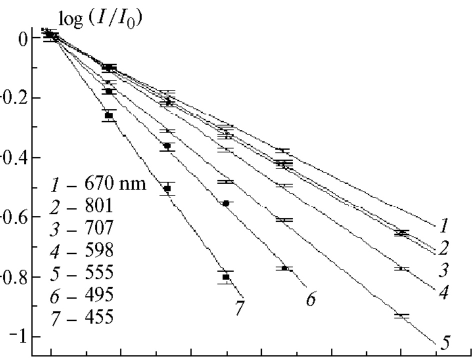

Fig. 1. An example of Bouguer lines (sample No. 5, before filtration).

As seen from Fig. 1, the 16-cm thick water layer can attenuate the light flux by more than one order of magnitude. The lack of ordering in the straight line location depending on the wavelength λ has attracted our attention. It is hardly possible that these spectral variations of transmission are connected with light scattering by the complex polymodal structures of hydrosol. Most likely, the spectral transmission variations are due to the presence of colored particles in water that have characteristic spectral absorption bands. The data given in Table 1 show that the water color varies depending on the coordinates of the points where sampling has been done. The table also shows the temperature values of the surface layer and the value of pH. High temperature of the upper layer reaching 26°C points to strong absorption of solar radiation by hydrosol. The values of pH are close to 7, i.e., its acidity is almost normal.

Table 2 gives the results of measurements of decimal light extinction coefficients σ (m^{-1}) and the corresponding errors for 13 water samples, whose intake points are shown on the map in Fig. 2. The marked variations of the value σ(λ) are observed. These variations determine the color blends given in Table 1. The differences in the spectral behavior of the extinction coefficients in the short-wave spectral range were discussed by the other authors.[8] The mean spectral dependences of $\overline{\sigma(\lambda)} / \sigma(555\text{nm})$ for the entire route and the corresponding root-mean-square deviations are shown in Fig. 3.

Almost neutral behavior of $\overline{\sigma(\lambda)}$ in the long-wave spectral range and the tendency towards its increase with the decreasing wavelength have attracted our attention. On the whole, high pollution of the River Ob by hydrosol is observed. It exceeds the pollution, for example, in the Ladozhskoe Ozero or Rybinskoe Reservoir.[4,6]

Table 1. Identification of water samples

No. of a sample	Coordinates of the points of water sampling		Data / Time	pH of water	*t*	Location	Water color
1	56 35′48″ N	84 47′02″ E	12.07.99/4.00	8.64	25.8	The River Tom, ~15 km downstream the city of Tomsk	Yellow-brown
2	56 56′37″	84 25′31″	12.07.99/8.45	8.59	25.4	The River Ob, 300 m downstream the mouth of the River Tom	Gray-green
3	57 43′23″	83 48′31″	13.07.99/11.30	7.91	25.5	The River Ob, 700 m below the River Chulym mouth	Gray-brown
4	58 17′45″	83 00′08″	14.07.99/5.13	7.81	25.5	The River Ob, ~10 km upstream of Kolpashevo town	Light-brown
5	58 33′44″	82 12′04″	15.07.99/7.11	7.62	25.8	The River Ob between the mouths of the rivers Chulym and Ket'	Red-grayish-brown
6	59 03′43″	80 52′13″	16.07.99/6.15	7.87	26.4	The River Ob opposite the pier of Kargasok	Dark-yellow
7	59 06′29″	80 44′32″	18.07.99/9.24	7.65	25.6	The River Ob, 500 m downstream the mouth of the River Vasyugan	Yellow-brown
8	59 13′24″	80 33′38″	19.07.99/16.00	7.14	24.8	The River Ob, the village Karga	Brown-yellow
9	60 26′04″	77 52′16″	20.07.99/17.00	7.75	22.1	The River Ob opposite the pier of Aleksandrovo village	Dark-yellow
10	60 48′10″	76 46′28″	22.07.99/–	7.63	20.8	The River Ob, 2 km downstream the mouth of River Vakh	Light-yellow
11	61 00′31″	76 03′25″	23.07.99/3.00	7.50	21.5	The River Ob, the city of Surgut	Yellow-brown
12	61 02′34″	75 32′00″	23.07.99/6.06	–	21.4	The River Ob, ~30 km downstream Surgut	Brown-green
13	61 05′59″	68 48′59″	25.07.99/4.16	–	21.5	The River Ob, 1.5 km downstream the mouth of the River Irtysh	Brown

Table 2. Extinction coefficient of natural water (m^{-1})

Wave-length, nm	Sample number																									
	1		2		3		4		5		6		7		8		9		10		11		12		13	
	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ
455	–	–	–	–	3.42	0.06	6.61	0.19	10.24	0.31	6.65	0.06	5.84	0.22	7.61	0.09	7.85	0.04	10.23	0.30	8.90	0.13	5.86	0.16	6.80	0.19
495	2.97	0.04	2.69	0.04	4.17	0.15	5.80	0.12	7.74	0.15	7.74	0.13	5.15	0.08	5.48	0.05	6.52	0.12	9.65	0.31	7.31	0.14	5.89	0.05	7.11	0.10
555	2.76	0.11	2.43	0.05	2.31	0.07	4.68	0.07	6.26	0.09	7.26	0.05	3.75	0.08	5.01	0.15	5.63	0.08	6.48	0.08	6.48	0.08	6.03	0.13	4.69	0.20
598	2.66	0.12	2.12	0.02	3.94	0.04	5.36	0.07	5.27	0.10	6.43	0.13	4.00	0.06	4.23	0.12	4.40	0.05	5.62	0.24	2.87	0.12	5.45	0.25	6.20	0.22
670	2.59	0.09	2.13	0.08	3.97	0.07	6.58	0.14	3.86	0.14	4.64	0.10	3.09	0.06	3.74	0.06	3.82	0.03	5.36	0.15	4.65	0.02	5.78	0.04	3.67	0.19
707	3.03	0.09	2.59	0.09	3.73	0.07	6.90	0.04	4.47	0.05	6.91	0.32	3.55	0.02	4.48	0.06	4.47	0.08	4.31	0.06	4.15	0.01	4.81	0.04	3.95	0.10
801	3.99	0.08	2.68	0.06	3.19	0.17	6.64	0.10	4.41	0.06	7.22	0.31	3.11	0.17	4.39	0.09	4.31	0.06	4.99	0.05	3.63	0.03	4.39	0.13	3.36	0.11

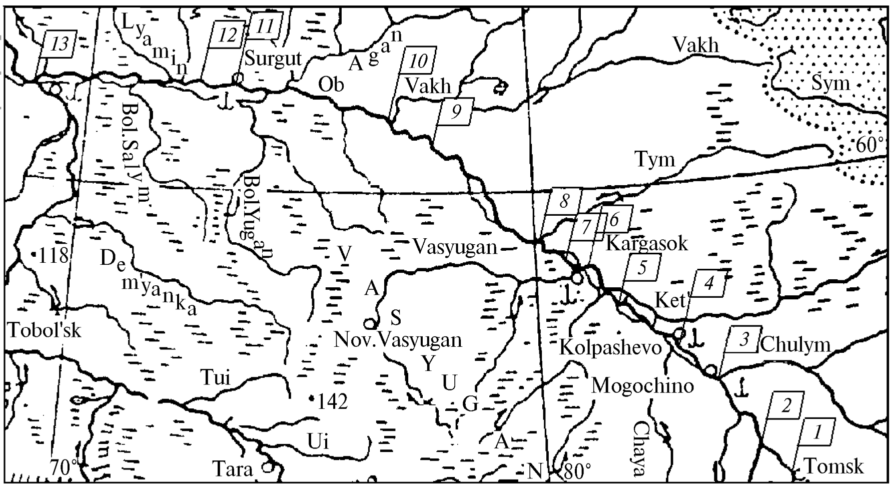

Fig. 2. The map of water sampling points.

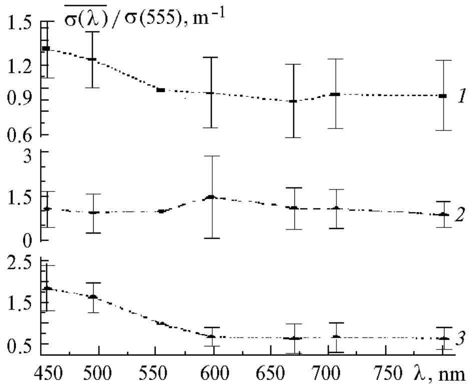

Fig. 3. Spectral dependences averaged over the entire route: $\sigma(\lambda)/\sigma(555\ \text{nm})$ (*1*), $\sigma_c(\lambda)/\sigma_c(555\ \text{nm})$ (*2*), and $\sigma'_m(\lambda)/\sigma'_m(555\ \text{nm})$ (*3*).

Similar spectral dependences occur traditionally when the particle color is reddish-yellow. These colors dominate in the River Ob water to the north of the mouth of the River Chaya. The above colors are mainly conditioned by the outflow of the remains of decomposed vegetation cover from the marshes of the Western-Siberian lowland (so-called yellow substance) to the River Ob. Phytoplankton and the particles of mineral origin enriched with the iron oxides can also have a pronounced effect on the water color. The oxides of iron exist copiously in the Middle Ob floodplain.

To determine the contribution of large and small hydrosols to the total extinction coefficient, the successive water filtration was performed using standard chemical filters "red band" and "blue band" with the transmission pores of 10 and 2.5 μm, respectively. After this procedure we measured the extinction coefficients of filtered out water $\sigma_m(\lambda)$ containing particles with the diameters $d < 2.5$ μm. In this case the difference $\sigma_c(\lambda) = \sigma(\lambda) - \sigma_m(\lambda)$ characterizes the extinction by large hydrosol with $d > 2.5$ μm. Tables 3–4 show the values $\sigma_c(\lambda)$ and $\sigma'_m(\lambda) = \sigma_m(\lambda) - \sigma_n(\lambda)$, where $\sigma_n(\lambda)$ is the absorption coefficient of clean water,[7] $\sigma'_m(\lambda)$ is the extinction coefficient of hydrosol with $d < 2.5$ μm and dissolved matter. Table 5 shows the corresponding concentrations of dry residue of particles deposited on the filters of both types as well as their sum values. Using the data from these tables we can judge on the marked spectral variations of $\sigma_c(\lambda)$ and $\sigma'_m(\lambda)$ at different sampling points and the absence of correlation between these values and the dry residue concentration. The latter is quite natural, since in drying the filters, the organic hydrosol, in contrast to mineral particles, changes its mass not to mention "the disappearance" of microscopic air bubbles contributing to light scattering.

Table 3. Extinction coefficient of hydrosol [coarse fraction ($d > 2.5$ μm)], m^{-1}

Wave-length, nm	Sample number																							
	1		2		3		4		6		7		8		9		10		11		12		13	
	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ
455	–	–	–	–	1.27	0.09	5.22	0.19	0.67	0.45	1.19	0.34	3.91	0.11	2.91	0.31	4.72	0.32	3.69	0.13	0.55	0.19	1.93	0.20
495	0.94	0.05	1.41	0.05	2.67	0.19	5.02	0.12	2.25	0.15	1.50	0.29	2.38	0.07	2.44	0.13	4.98	0.31	1.75	0.25	0.21	0.12	0.26	0.10
555	1.66	0.12	1.48	0.06	1.62	0.09	4.00	0.08	4.30	0.05	0.61	0.19	2.43	0.17	2.93	0.12	3.41	0.11	3.44	0.10	2.89	0.21	0.90	0.24
598	1.36	0.14	1.65	0.03	3.18	0.05	4.65	0.08	3.76	0.25	2.28	0.08	1.86	0.12	2.35	0.11	2.91	0.24	0.41	0.16	2.91	0.27	4.51	0.22
670	1.74	0.10	1.37	0.08	2.98	0.09	5.81	0.14	1.93	0.12	1.60	0.07	1.96	0.10	2.15	0.06	3.48	0.16	1.54	0.11	0.54	0.09	1.67	0.20
707	1.08	0.12	2.09	0.10	2.61	0.07	6.14	0.05	4.31	0.38	0.93	0.05	2.22	0.07	2.68	0.12	2.80	0.08	0.28	0.04	0.73	0.25	2.26	0.18
801	2.23	0.11	1.85	0.06	1.93	0.18	5.13	0.10	3.97	0.34	0.59	0.23	2.07	0.10	2.88	0.06	2.62	0.08	0.13	0.03	0.11	0.02	0.99	0.12

Table 4. Extinction coefficient of hydrosol [medium and fine fractions and dissolved substances ($d < 2.5$ μm)], m^{-1}

Wave-length, nm	Sample number																							
	1		2		3		4		6		7		8		9		10		11		12		13	
	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ	σ	Δσ
455	–	–	–	–	2.12	0.06	1.38	0.01	5.95	0.45	4.45	0.26	3.68	0.05	4.93	0.30	5.70	0.11	5.20	0.01	5.30	0.11	4.85	0.05
495	2.00	0.03	1.24	0.02	1.47	0.11	0.75	0.02	5.47	0.07	3.63	0.28	3.07	0.04	4.05	0.05	4.64	0.04	5.53	0.21	5.65	0.11	6.82	0.02
555	1.03	0.03	0.88	0.02	0.62	0.06	0.62	0.03	2.89	0.03	3.07	0.17	2.51	0.09	2.63	0.09	3.01	0.08	2.98	0.07	3.08	0.17	3.71	0.15
598	1.04	0.07	0.21	0.02	0.50	0.03	0.45	0.04	2.41	0.21	1.45	0.05	2.11	0.02	1.79	0.10	2.45	0.01	2.18	0.11	2.28	0.09	1.43	0.02
670	0.43	0.05	0.35	0.01	0.57	0.07	0.35	0.02	2.29	0.07	1.06	0.02	1.37	0.07	1.25	0.05	1.46	0.06	2.69	0.11	4.81	0.08	1.58	0.06
707	1.15	0.08	–	–	0.31	0.01	–	–	1.79	0.20	1.81	0.04	1.45	0.04	0.98	0.08	0.69	0.05	3.07	0.04	3.24	0.24	0.89	0.15
801	0.80	0.08	–	–	0.29	0.05	0.54	0.04	2.29	0.14	1.55	0.16	1.35	0.04	0.46	0.01	1.40	0.07	2.52	0.01	3.31	0.18	1.41	0.05

Table 5. Hydrosol concentration [coarse fraction ($d > 10$ μm and $10 > d > 2.5$ μm)], g/l

Chemical filter	Sample number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Red band	0.0189	0.0998	0.0612	–	0.0549	0.0725	0.0359	0.0548	0.0453	0.0381	0.0279	0.0061	0.0284
Blue band	0.0268	0.0469	0.0470	–	0.0280	0.0341	0.0195	0.0209	0.0172	0.0068	0.0173	0.0416	0.0431

The spectral dependences $\sigma_c(\lambda)/\sigma_c(555\ \text{nm})$ and $\sigma_m(\lambda)/\sigma_m(555\ \text{nm})$, averaged over the entire route, are shown in Fig. 3. It is seen from the figure that, on the average, coarse hydrosols scatter light almost neutrally whereas for the particles with $d < 2.5$ μm and the dissolved organic matter the extinction coefficient increases with the decreasing wavelength. Consequently, it is precisely small particles and dissolved organic matter that are responsible for yellow color of water in the River Ob to the north of the mouth of the River Chaya that agrees with the literature data on physicochemical characteristics of the yellow substance.[7]

Acknowledgments

The authors would like to thank the leaders of the International Research Center for the Environmental Physics and Ecology of Tomsk Scientific Center, SB RAS, Academician of RAS V.E. Zuev, and Corresponding Member of RAS V.V. Zuev for the presented opportunity to take part in the field investigations, E.A. Karnaukhova for active participation in the development of instrumentation, as well as the scientists from the Limnology Institute SB RAS O.G. Netsvetaeva and N.A. Kobeleva for the measurements of the temperature and pH in water samples.

The work has been supported by the Russian Foundation for Basic Research (Grants: "98–Siberia", No. 98–05–03153 and 98–05–03154).

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