REMOTE SENSING OF ATMOSPHERE, HYDROSPHERE, AND UNDERLYING SURFACE

Method for Sea Water Absorption Spectra Estimation on the Basis of Shipboard Passive Remote Sensing Data and Pure Sea Water Properties

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Abstract—An original method for calibration of spectra of the seawater surface radiance coefficient measured from onboard a moving ship with a three-channel optical spectrophotometer is proposed. The method is based on some characteristics of pure sea water absorption. Using this method, the sea water absorption spectra can be retrieved. Results of processing measurements in the Russian coastal area of the Black Sea near river mouths are given. The efficiency of the calibration method for radiance spectra measurements under variable clouds and wind is shown. The concentrations of the main natural seawater admixtures have been estimated from the absorption spectra retrieved, and the estimates have been compared with contact measurements in water samples. It is shown that the method developed for sea water analysis, which includes remote shipboard measurements of the seawater brightness coefficient, calibration of the spectra, seawater absorption spectra retrieval, and estimation of the main seawater admixture concentrations, can be used for the study of shelf and inland seawater areas because it does not imply any correlation between phytoplankton, dissolved organic matter (yellow substance), and suspended matter concentrations.

Keywords: spectra of the seawater surface radiance coefficient, sea water absorption and scattering, river mouth area of the Black Sea, main seawater admixture concentrations, phytoplankton, dissolved organic matter, yellow substance, suspended matter

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INTRODUCTION

Methods that include measurements of sea water optical properties are among the most efficient methods for seawater analysis. A bulk of data has been accumulated by now that allows one to correlate seawater optical properties with concentrations and compositions of the main natural seawater admixtures. The accumulated data on light absorption and scattering and fluorescence are basically composed by results of long-term studies of sea waters different in admixture compositions with the use of submersible and flow-through light transmittance meters, spectrophotometers, fluorometers, Secchi disk, and lidars [1−8].

Passive sensing methods allow recording solar fluxes scattered by the water column. Their magnitudes mainly depend on light absorption and scattering by seawater, since the sunlight-excited fluorescent response of the water is negligible. The seawater spectral brightness coefficient (SBC) is one of key seawater parameters measured with passive methods. The radiation flux outgoing from the seawater depth carries information about all optically active seawater components, each certainly influencing the spectrum profile [9−13].

However, shipboard measurements of the SBC spectrum are difficult, because it is necessary to dis-criminate between a signal from the water column and the surface-reflected sunlight. To exclude the reflected signal, a subsurface spectrophotometer has been designed for measurements of subsurface irradiance and radiation flux outgoing from the water depth; for operation, it requires submersion of the device at stations or towing devices [14, 15].

Three-channel radiometers were suggested for remote measurements of the SBC. They measure the brightness of upward and downward light fluxes and brightness of the sky area that mainly contributes to the water surface reflected signal. The SBC spectra were shipboard measured and processed [16−20]. However, it turned out that the resulting spectra strongly depend on the measurement conditions. This might well prevent the wide use of this technique. We suggest a calibration technique, which relieves the requirements for weather conditions, under which satisfactorily results can be obtained. The technique is based on consideration of light absorption and scattering by pure sea water, almost free of suspended or dissolved admixtures.

The SBC remote measurement technique can be especially useful when it is required to develop or refine a regional satellite data decoding algorithm related to a specific water body and season (see, e.g.,

[21−23]). In this case, minimally required shipboard (contact) measurements should be supplemented with measurements of parameters of the upward radiation flux which has already entered the atmosphere but has not been affected by it. Only in such a case can the atmospheric effect be taken into account correctly. In addition, rapid sensing methods should be used to acquire data sufficient for the development of a regional decoding algorithm in coastal water areas and inner seas (water type 2 [1, 2]), in view of the strong spatiotemporal variability of their parameters. A high resolution is of special importance during monitoring of coastal water areas impacted by continental runoff.

In this work, a method is described for SBC measurements from onboard a moving ship with a three-channel optical spectrophotometer. A new calibration technique is suggested, which allows the use of spectra measured in cloudy and windy conditions. The spectral coefficients of water absorption are retrieved from the spectra measured, and the concentrations of main sea water admixtures are estimated in the region under study.

SBC SPECTRA MEASURED DURING SHIPBOARD REMOTE SENSING

The SBC is defined as the ratio of the brightness of radiation outgoing from the water depth to the brightness of a horizontal perfectly scattering surface that characterizes the solar irradiation of the water surface:

$$\rho(\lambda) = \frac{B_{up}}{B_{down}}. \qquad (1)$$

Expressing the magnitude of radiation ascending from a thin water layer in terms of coefficients of light backscattering and absorption in this layer and integrating throughout the water column (the coefficients are taken to be averaged over the sun-illuminated layer), the equation for SBC in terms of the optical parameters of water can be derived [3, 4]:

$$\rho(\lambda) = \frac{k_0 b_b(\lambda)}{a(\lambda) + b_b(\lambda)}, \qquad (2)$$

where $b_b(\lambda)$ is the coefficient of water column backscattering; $a(\lambda)$ is the water absorption coefficient; k_0 is a certain constant determined by light transmission through the water−air interface.

To calculate SBC, three parameters were shipboard measured at each point: the upward radiation brightness, which includes the brightness of radiation scattered by the water column and brightness of sunlight reflected by the seawater surface, the brightness of the sky area that mainly contributes to the reflected radiation, and the brightness of a horizontal white diffuse reflector, which characterizes the seawater surface

irradiation. Seawater SBC has been estimated by the equation

$$R(\lambda) = \frac{B_{sea} - rB_{sky}}{B_{ws}}, \qquad (3)$$

where B_{sea} is the brightness of radiation flux from the sea water, B_{sky} is the brightness of the related sky region, r is the Fresnel reflection coefficient equal to 0.02 in calm weather and at near-vertical sensing directions, and B_{ws} is the white reflector brightness. The light absorption and scattering by air is ignored, since the shipboard sea surface sensing is considered.

Figure 1 shows the brightness spectra, which were measured in the north-eastern part of the Black Sea near the Vulan river estuary at four points while the ship was moving away from the coast. An AVANTES spectrophotometer with the spectral range 360−760 nm, spectral resolution of 5 nm, signal-to-noise ratio of 1000 : 1, and integration time from 0.1 to 60 s was used for the measurements. It is seen that though the general behavior of the spectra retains, the brightness of objects under study varies significantly because of clouds and strong wind, which change the irradiation conditions when changing from one object to another (thus, the object brightness changes by 3−4 times due to direct sunlight shadowing by clouds). SBC spectra calculated from these measurements are shown in Fig. 1d.

The SBC error in Eq. (3), calculated by the signal-to-noise ratio of the spectrophotometer and with ordinary relations for the error of the sum and quotient of two parameters, is approximately equal to 1% in the range 400−600 nm and increases when measuring small magnitudes in the 600−700 nm range. The measurement error can be estimated directly from the SBC spectra calculated, considering deviations from the midline in small spectral ranges (~30 nm) as results of measurement errors. It is seen (Fig. 1d) that the absolute error is approximately equal throughout the spectrum (~0.001 for two top curves). Hence, the relative error changes from 2 to 5% and a little more in the 600−700 nm range. However, in-motion shipboard measurements under conditions of partly cloudy, heavy sea, or quickly varying optical parameters of the water mass under study contribute a much higher error when using a remote method. In addition, during successive measurements of sea, sky, and white reflector brightness (which were used for SBC spectra in this work), an additional error is caused by asynchronicity of the readings. A prototype of a new-generation three-channel spectrophotometer is currently designed; it is capable of measuring synchronously the three above parameters. In addition, a calibration technique described below provides for satisfactory spectra, which allows estimation of the admixture concentrations from onboard a moving ship, even under bad weather and incomplete synchronization of individual measurements.
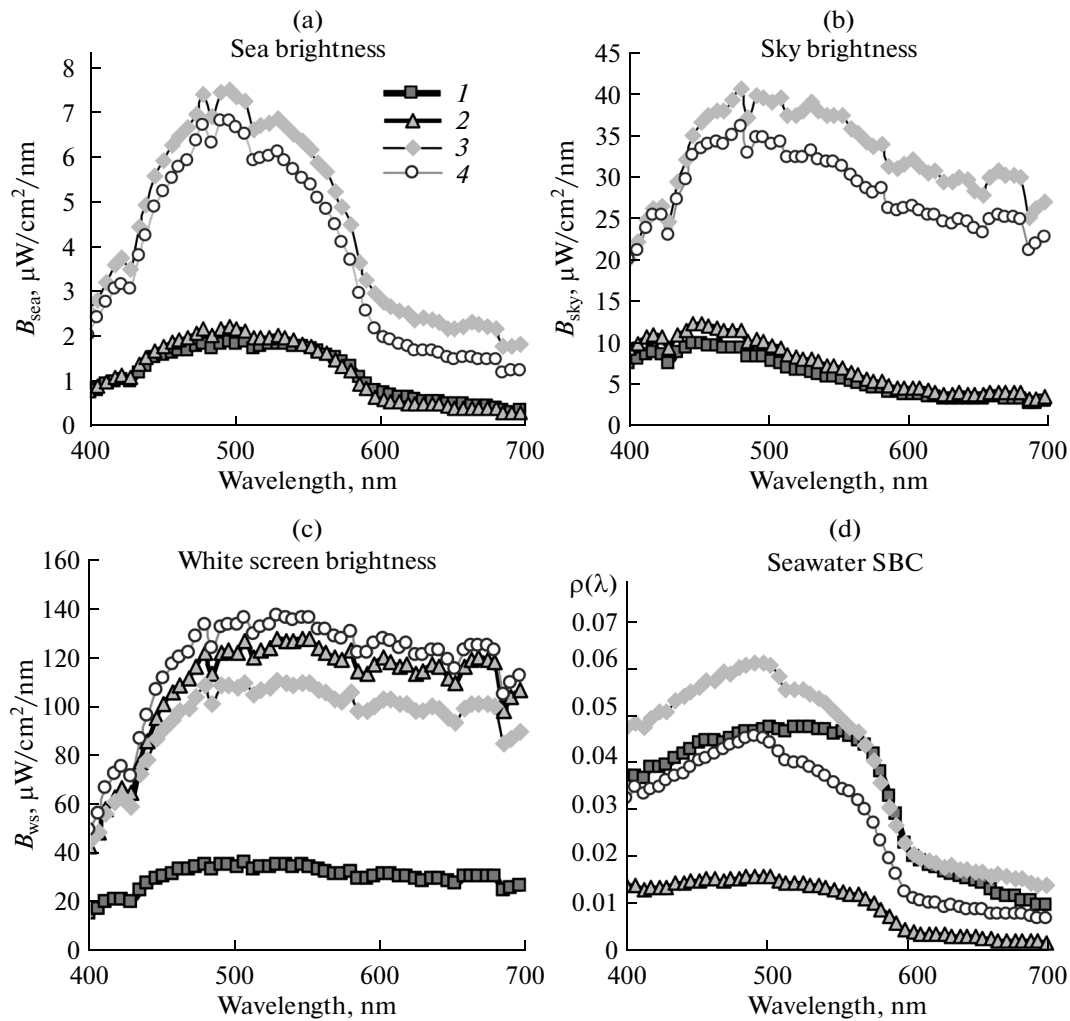
Fig. 1. (a) Brightness spectra of radiation propagating upward from the sea water surface measured in the 400−700 nm range, (b) brightness spectra of the sky area that mainly contributes to the light reflection from the water surface during SBC measurements, and (c) brightness of a horizontal white opaque screen; (d) SBC spectra calculated from these data. Curves *1−4* have been calculated while the ship was moving away from the coast.

SBC SPECTRA CALIBRATION USING PURE SEA WATER ABSORPTION PECULIARITIES

The idea of the calibration appeared from the comparison of SBC spectra received in different seas. A certain common feature of the spectra was revealed, i.e., the presence of a knee in the 580−630 nm (clearly seen in Fig. 1). The light absorption and scattering by natural sea water admixtures (chlorophyll, yellow substance, and suspended matter) have no peculiarities in this spectral range. The light absorption by pure sea water is usually higher than the light absorption by admixtures in this range and increases with the wavelength, and this increase rapidly slows down at 600 nm (Fig. 2) [5, 24−26]. Just this peculiarity served as a basis for the calibration of SBC dependence calculated and the calculation of water absorption spectra.

The suggested calibration technique by pure water absorption consists of several iteration steps. During the first step, the backscattering coefficient b_b is considered independent of the wavelength in the 580−700 nm range, and the absorption coefficient of phytoplankton pigments a_p and yellow substance a_{ys} are considered small as compared to the absorption coefficients of pure water a_w and suspended matter a_{sm}. Assumption about the scattering is true for the most part of coastal waters, since the backscattering here is mainly determined by scattering by the suspended matter b_{sm}, and variations in the spectral curves depend on scattering by fluctuation inhomogeneities of water b_w. The absorption by yellow substance and phytoplankton pigments is much lower than the absorption by pure water ($\ll 0.1\,\mathrm{m}^{-1}$) in this range. Hence, the following equations can be written at the first step:

$$b_b \approx b_{w600} + b_{sm} = b_{600} = \mathrm{const},$$
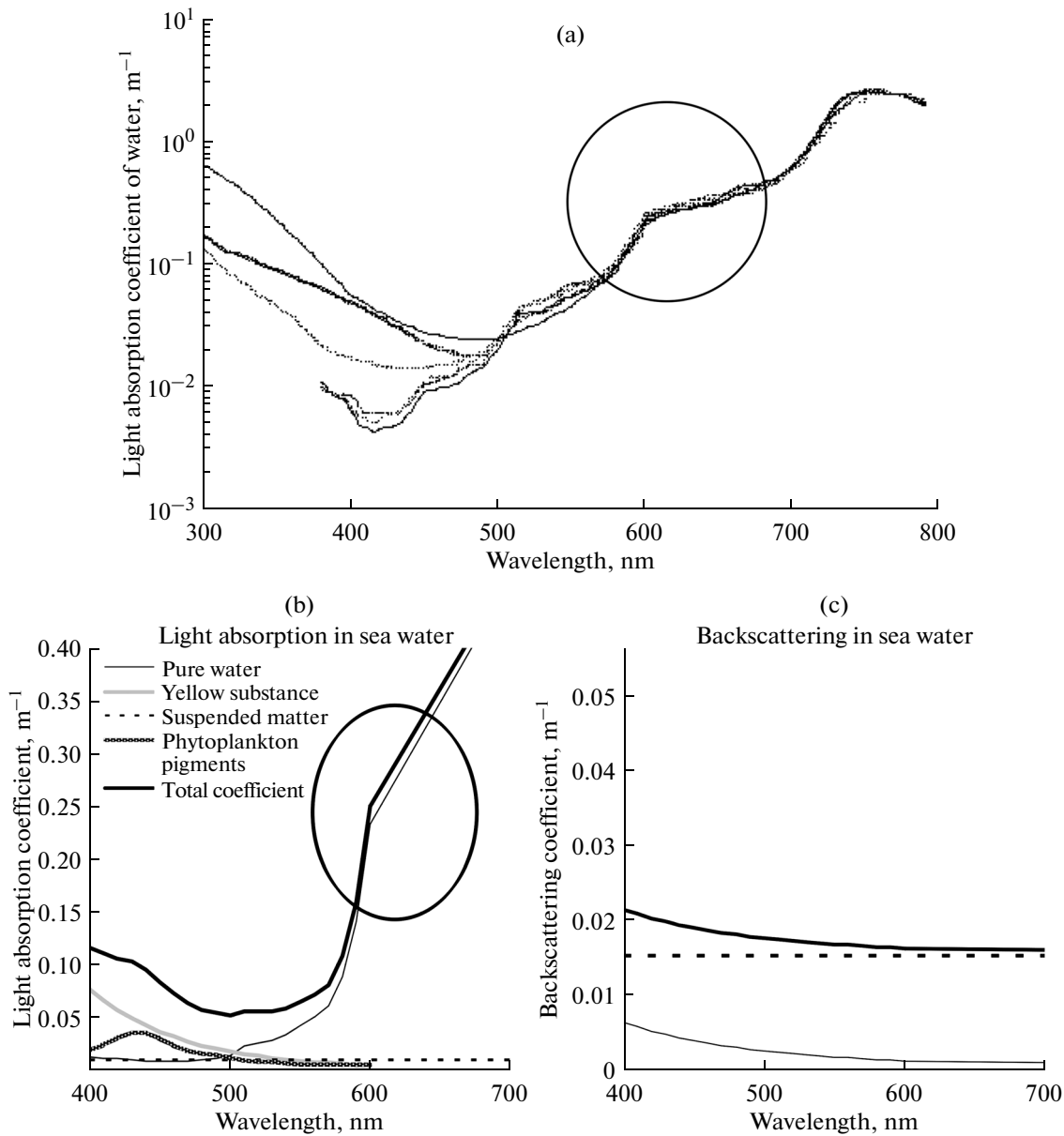$$a_p, a_{ys} \ll a_w + a_{sm} \text{ at } 580 < \lambda < 700 \text{ nm.} \tag{4}$$

Fig. 2. (a) Pure sea water absorption spectrum [5]: the wavelength dependence of the absorption stepwise changes near 600 nm. (b) Absorption and backscattering spectra for water and main sea water admixtures: only the water absorption has a peculiarity at 600 nm.

Let assume at the first step that the difference in the absorption before and after the knee at 600 nm is provided only by pure water absorption in this range, i.e., it is known in advance:

$$\Delta_1 = a_{w700} - a_{w600},$$
$$\Delta_2 = a_{w600} - a_{w580}, \qquad (5)$$

and one can write

$$a_{700} = a_{600} + \Delta_1,$$
$$a_{580} = a_{600} - \Delta_2. \qquad (6)$$

It should be noted that the absorption coefficients can be equal to not only the absorption coefficient of pure water, but are a sum of absorption by pure water and suspended matter (the absorption coefficient of the latter is considered constant, in the opposite case the calibration technique is to be refined).

Let us assume that the different weather factors cause the difference between the true SBC and the measured value and can be calculated by the equation

$$\rho(\lambda) = kR(\lambda) - \Delta R, \qquad (7)$$

where $R(\lambda)$ is the spectrum calculated by the measurements; and k and ΔR are the unknown coefficients. Nonselectivity of the coefficient k and difference ΔR in Eq. (7) was assumed from the analysis of possible causes

of the appearance of these corrections. Thus, the coefficient k different from unity appears during a stepwise change in the total illumination, during which the relative spectral distribution does not change (see Fig. 1c), hence, k is nonselective. The nonzero coefficient ΔR appears when the sky brightness is incorrectly taken into account, but it also changes stepwise, and the quotient of sky brightness by white reflector brightness is almost constant in the 580–700 nm range. A certain nonlinearity can appear here near 500 nm, and it can be taken into account during calculation of the absorption spectra. However, ΔR turned out small in our measurements and was considered constant to the first approximation. Later, this correction can be introduced. Substitution of Eq. (2) in the left part results in the equation

$$\frac{k_0 b_b}{a + b_b} = kR - \Delta R. \tag{8}$$

Considering Eqs. (4)–(6), the set of equations for three SBC values measured at 580, 600, and 700 nm can be written for the red spectral region:

$$\begin{cases} \dfrac{1}{a_{600} + b_{600} - \Delta_2} = \dfrac{k}{k_0 b_{600}} R_{580} - \dfrac{\Delta R}{k_0 b_{600}}, \\[2mm] \dfrac{1}{a_{600} + b_{600}} = \dfrac{k}{k_0 b_{600}} R_{600} - \dfrac{\Delta R}{k_0 b_{600}}, \\[2mm] \dfrac{1}{a_{600} + b_{600} + \Delta_1} = \dfrac{k}{k_0 b_{600}} R_{700} - \dfrac{\Delta R}{k_0 b_{600}}. \end{cases} \tag{9}$$

This is the set of three equations with three unknowns $a_{600} + b_{600}$, $\dfrac{k}{k_0 b_{600}}$, and $\dfrac{\Delta R}{k_0 b_{600}}$. Solving this set relative to these three unknowns and substituting them in Eq. (8), the spectra of the parameter connected with the water absorption and scattering can be estimated in the whole measurement spectrum range (400–700 m):

$$\frac{a(\lambda) + b_b(\lambda)}{b_b(\lambda)/b_{600}} = \left[\frac{k}{k_0 b_{600}} R(\lambda) - \frac{\Delta R}{k_0 b_{600}} \right]^{-1}. \tag{10}$$

It should be noted here that equation (10) estimates the water absorption spectrum for mesotrophic and eutrophic waters, which mainly occur in shelf zones, since the scattering is determined here by scattering by suspended matter, which can be considered more or less independent of the wavelength in the chosen range. Indeed, assuming $b_b(\lambda) \approx b_{600} + \delta b_\lambda$, where $\delta b_\lambda \ll b_{600}$, we derive

$$\frac{a(\lambda) + b_b(\lambda)}{b_b(\lambda)/b_{600}} \approx a(\lambda) + b_{600} - a(\lambda)\left(\frac{\delta b_\lambda}{b_{600}}\right). \tag{11}$$

Neglecting the third term, one can conclude that the resulting spectrum is the water absorption spectrum plus a constant which shows the mean backscattering.

At the second iteration step, the corrections to the difference in water absorption coefficients Δ_1 and Δ_2 introduced by yellow substance and pigments can be

taken into account. For this, let us estimate a change in absorption by the admixtures (a_{xyz}) in the spectrum when changing from 500 to 600 nm:

$$a_{xyz500} - a_{xyz600}$$
$$= \left(\left[\frac{k}{k_0 b_{600}} R(500) - \frac{\Delta R}{k_0 b_{600}} \right]^{-1} - a_{w500} \right) \tag{12}$$
$$- (a_{600} + b_{600} - a_{w600}).$$

Assuming that the total absorption by yellow substance and pigments (a_{xy}) exponentially decreases with the wavelength in the 500–700 nm range and the exponent is equal to the exponent of the yellow substance absorption $g = 0.015$ nm^{-1} [18], we obtain

$$a_{xy}(\lambda) = a_{xy500} \exp(-g(\lambda - 500)),$$
$$a_{xy500} = \frac{a_{xyz500} - a_{xyz600}}{1 - \exp(-g(600 - 500))}. \tag{13}$$

Calculation of Δ_1 and Δ_2 by the absorption, which consists already of three components at this step (pure water absorption, nonselective absorption by suspended matter, and total absorption by yellow substance and pigments) is carried out by the equations

$$\Delta_1 = a_{w700} - a_{w600} + a_{xy500}$$
$$\times (\exp[-g(700 - 500)] - \exp[-g(600 - 500)]),$$
$$\Delta_2 = a_{w600} - a_{w580} + a_{xy500}$$
$$\times (\exp[-g(600 - 500)] - \exp[-g(580 - 500)]). \tag{14}$$

Then, the set of equations (9) is solved with new values of Δ_1 and Δ_2. The iteration steps continue until the difference between a_{xy500} at the next and previous steps becomes smaller than a certain preset value. Table 1 shows values calculated during three iteration steps by the SBC spectrum measured at four points when moving away from the coast. It is seen that a_{xy500} at the third step differs from the previous value by no more than 1%.

After a required number of iterations, the resulting coefficients are substituted in Eq. (10), and the total spectrum of seawater absorption and the constant that corresponds to the mean scattering by suspended matter is calculated. Subtracting the known pure seawater absorption spectrum from it, the admixture absorption spectrum can be estimated. Figure 3 shows spectra calculated at four stations when moving away from the coast.

It is seen that these absorption spectra change orderly when moving away from the coast (and the river estuary), in contrast to the SBC spectra, which can hardly be systematized. The estimation error of the absorption spectra calculated with the use of the calibration suggested by Eq. (10) can be estimated from the spectra (Fig. 3). The relative error is 5–7% (the same result is found from estimation by the equation under the assumption that the pure seawater absorption is

Table 1. Estimates of the absorption coefficients of phytoplankton pigments and yellow substance at 500 nm by three iterations for four stations

Absorption coefficient, m^{-1}	Station no.			
	1 (coastal)	2 (~0.7 km from the coast)	3 (~1.5 km from the coast)	4 (~2.2 km from the coast)
$a_{xy\,500}$ [I]	0.0388	0.0108	0.0094	0.0234
$a_{xy\,500}$ [II]	0.0435	0.0122	0.0106	0.0263
$a_{xy\,500}$ [III]	0.0441	0.0124	0.0108	0.0267

Table 2. Estimates of phytoplankton pigments, yellow substance, and suspended matter concentrations in seawater by the absorption spectra calculated from shipboard remotely measured SBC. The concentrations measured in water samples are given in italics for comparison

Concentration	Station no.				Concentration range in the samples
	1 (coastal)	2 (~0.7 km from the coast)	3 (~1.5 km from the coast)	4 (~2.2 km from the coast)	
C_p, mg/m^3	1.35 *0.4*	0.45 *0.9*	0.45 *0.6*	0.6 *0.5*	*0.4–0.9*
$a_{ys\,500}$, m^{-1}	0.012 *0.04*	0.007 *0.02*	0.007 *0.02*	0.008 *0.005*	*0.005–0.04*
$a_{sm} + b$, m^{-1}	0.14 *0.02*	0.06 *0.008*	0.05 *0.009*	0.015 *0.004*	*0.004–0.02*

known with an accuracy higher than during our measurements). The absolute error is about 0.005 m^{-1} in the 400–580 nm range and attains 0.02 m^{-1} in the 600–700 nm range, since the absorption significantly increases in this range (let us note that the absolute error does not decrease when subtracting the pure water absorption; therefore, the range 600–700 nm is excluded from the estimation of admixture concentrations). Using these spectra, the concentration of the main seawater admixture can be estimated.

ESTIMATION OF CONCENTATIONS OF MAIN SEAWATER ADMIXTURES

The estimation of the concentrations of the main natural seawater admixtures is exemplified below by processing the absorption spectrum that has been calculated at stations no. 1 the nearest to the coast (Table 2).

The main light absorbing and scattering components are phytoplankton pigments, with an absorption maximum at 430 nm, dissolved organic matter (yellow substance) and detritus, with the spectrum that exponentially decreases with the wavelength, and suspended matter, with the absorption and scattering independent of the wavelength in the range 400–700 nm. The seawater absorption can be written as [16]:

$$a(\lambda) = a_w(\lambda) + C_p a_p^*(\lambda) \\ + a_{ys\lambda_0} \exp(-g(\lambda - \lambda_0)) + a_{sm}. \quad (15)$$

Here, $a_w(\lambda)$ is the absorption coefficient of pure seawater (without admixtures); a_{sm} is the light absorption coefficient of seawater suspended matter (its absorption and scattering can be considered independent of the wavelength in the range under study for a wide
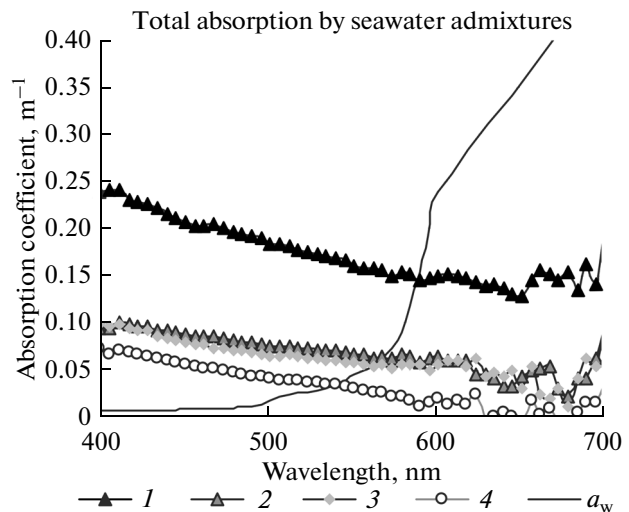

Fig. 3. Seawater absorption spectra calculated with the use of the technique suggested for calibration by SBC shipboard remotely measured on the site near the Vulan river estuary. The darker curves correspond to stations closer to the coast; the thin curve shows the pure sea water absorption spectrum.
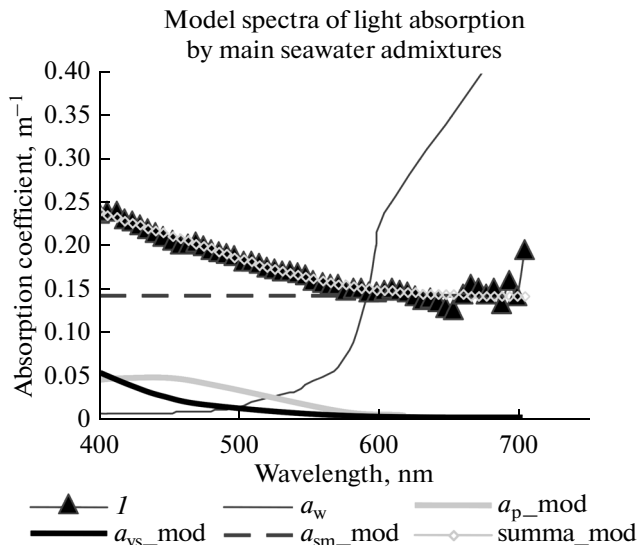
Model spectra of light absorption
by main seawater admixtures

Fig. 4. Estimates of the concentrations of the main seawater admixtures from the absorption spectrum (station no. 1). The admixture absorption spectrum calculated by the SBC spectrum is shown by dark triangles. The calculated light absorption spectra of natural admixtures (phytoplankton, yellow substance, and suspended matter) with the most probable concentrations are shown by curves of different thickness and tint: a_{p}_mod corresponds to the phytoplankton pigments, a_{ys}_mod, to yellow substance, and a_{sm}_mod, to suspended matter. Empty diamonds show their total absorption spectrum.

range of problems); C_p and $a_p^*(\lambda)$ are the concentration and specific absorbance of phytoplankton pigments; $a_{\mathrm{ys}\lambda_0}$ is the absorption coefficient of colored dissolved organic matter (yellow substance) and detritus (colored organic matter in the suspended matter), contained in seawater, at the wavelength λ_0; and g is the factor equal to $0.011-0.02\ \mathrm{nm^{-1}}$; here $g = 0.015\ \mathrm{nm^{-1}}$, $\lambda_0 = 500\ \mathrm{nm}$. Hereinafter, the values of all these parameter refer to the average values over the surface water layer the solar radiation penetrates into.

Setting the specific absorption spectra of the main admixtures according to the available data [4, 5], one can calculate the seawater absorption spectrum at different admixture concentrations and compare it with the absorption spectrum found from SBC. Varying the concentrations, one can choose values at which the deviation between the two curves is minimal (e.g., by the mean square method). The curves are compared in the range 400–600 nm, since the spread in absorption values is larger in the longer wavelength range because of the small SBC comparable with signal fluctuations. Figure 4 shows the results of the procedure, i.e., model curves for absorption by phytoplankton pigments, yellow substance, and dissolved matter and the total model spectrum, which agrees well with the absorption spectrum calculated by SBC.

The admixture concentrations have been calculated by the resulting spectrum. To calculate the phy-

toplankton pigment concentration, the empirical dependence of the concentration on the absorption maximum at 430 nm has been used, which has been derived in water samples in the same experiment; the concentrations of yellow substance and suspended matter have been found by absorption at 500 nm. It is important to emphasize here that all estimates have been found without an assumption about any correlation of these concentrations, which is a necessary condition for operation in shelf waters (water type 2).

Carrying our similar calculations for all stations, the table of the admixture concentrations averaged over the sun illuminated layer has been composed. The concentrations of all the three admixtures tend to decrease as the distance from the coast increases. The concentrations found in surface water samples are given in Table 2 for comparison. The concentration error has been calculated by means of variation in each concentration about the average, and the value has been selected for which the standard deviation of a new model curve from the spectrum measured differs from the deviation of the best model curve by no more than the spectrum measurement error.

The calculations performed allow the conclusion that the phytoplankton and suspended matter concentration errors are about 30% and the yellow substance concentration error is about 40%. Two remarks are required here: first, these estimates are applicable only to mesotrophic and eutrophic waters; second, the results of comparison with measurements in water samples do not refute the result, since our method allows estimating concentrations averaged over the sun-illuminated layer, while the samples were taken from the surface layer (it is of interest to compare tends in concentrations). It is seen that concentrations of phytoplankton pigments found by different methods are close except for coastal station no. 1 located near the river estuary. It is evident that the river water did not mix with the sea water, and estimates by surface water samples differ from estimates of the light penetration depth average absorption. The yellow substance concentrations found from the absorption spectrum slightly decrease when moving away from the coast. Similar estimates by water samples give a high spread in the values because they relate to the surface layer; however, they coincide with estimates from the spectrum on the order of magnitude and in a general trend. Suspended matter concentrations found by the spectra and in the samples differ significantly. This might well be due to rapid sedimentation of the suspended matter. At the same time, the trend toward a decrease in the suspended matter concentration as the distance from the coast increases is seen in the both cases.

DISCUSSION OF RESULTS

Thus, it is shown that the SBC of the upper sea layer calculated from shipboard measurements gives much information about the seawater composition.

This parameter can be measured with the use of a small and light three-channel spectrophotometer, which has no special requirements for supply. In addition, since the measurements are passive and remote and do not require special stops, they can be carried out onboard a moving vessel.

However, the resulting SBC spectra strongly depend on surveying conditions. This might well be the reason why this method for seawater analysis has not been commonly accepted. In view of this, the calibration technique suggested for SBC spectra recorded in bad weather (clouds and wind) significantly expands opportunities of using the shipboard passive remote measurements of SBC. The calibration is based on the use of absorption properties of pure seawater in the 580−700 nm range. The technique is convenient because the absorption by all main admixtures has no peculiarities in this range and is usually weak, while the required values of the seawater absorption are quite high and measured with good accuracy.

Another advantage of the technique is a possibility of retrieving the spectra of light absorption by seawater after the calibration. These spectra and known spectra of the specific absorbance of the main sea water admixtures can be used for estimation of the admixture concentrations. It is important that all the estimates do not imply any correlation between phytoplankton, dissolved organic matter (yellow substance), and suspended matter concentrations, which is a key point when operating in shelf waters and inner seas (water type 2).

The measurements carried out in the Black Sea near the river estuaries allowed testing the techniques for SBC measurement with a three-channel spectrophotometer, calibration of resulting spectra with calculation of the absorption spectra, and admixture concentration estimation in coastal waters. The resulting concentrations have been compared with the concentration measured in water samples taken in the same experiment. Correlations between the estimates allow a conclusion about the possibility of detecting the coastal water composition with the shipboard remote SBC measurement technique.

CONCLUSIONS

The inclusion of a new calibration technique described in this work, in the chain passive remote seawater SBC measurements−spectra calibration and calculation of admixture absorption spectra−sea water analysis makes the procedure more reliable and less dependent on the weather conditions.

Since the shipboard measurements can be carried out on move, the technique suggested can be convenient for mapping admixture distribution in the coastal water areas. In addition, it can be used in subsatellite measurements, especially for Russian satellites with onboard multispectral optical instrumentation.

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