USING INHERENT PROPERTIES OF SEAWATER ABSORPTION FOR ESTIMATION OF NATURAL ADMIXTURES CONCENTRATION FROM DATA OF OPTICAL PASSIVE REMOTE SENSING OF SEA SURFACE

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ABSTRACT

One of the most informative optical characteristics of the seawater that can be obtained by passive remote sensing is sea radiance coefficient spectrum. However, it is strongly affected by weather conditions and needs some calibration.

It was shown that practically all the spectra of sea radiance coefficient have some generic peculiarities regardless of the type of sea waters. These peculiarities can be explained by the spectrum of pure sea water absorption. Taking this into account a new calibration method was developed. In the spectrum of pure sea water absorption in the visible some narrow spectral bands were selected where water absorption changes far more rapidly than absorption in the neighboring bands and the optical properties (absorption and scattering) of the main sea water admixtures. That causes some typical peculiarities in the appropriate places of the sea radiance spectrum using which the spectrum of seawater absorption can be retrieved. After that taking into account the specific spectra of the main natural sea water admixtures it is possible to estimate their concentrations.

The efficiency of the suggested method was demonstrated for the spectra of sea radiance coefficient obtained at the north-east coast of the Black Sea with the portative spectrophotometer AVANTES from board a ship. Because of the Black Sea confined nature and strong interactions with the continent, its optical water properties differ from the open ocean water properties and often exhibit significant regional peculiarities especially in the areas of mixing with river waters. The obtained concentration estimates were compared to the values obtained in water samples taken during the same measurement cycle.

Thus, the suggested method enables to get sea radiance coefficient spectra and water absorption spectra of the aquatorium under investigation for wide range of the weather and measurement conditions. The obtained spectra can be successfully processed to estimate concentration of the three natural sea water admixtures – phytoplankton pigments, “yellow substance” and suspended matter. Using it for optical remote sensing from board a ship enables to get some necessary data during ground truth measurements. It is also necessary for exploring the sea areas which are too close to the coastal line or cannot be seen from satellites because of cloudiness.

INTRODUCTION

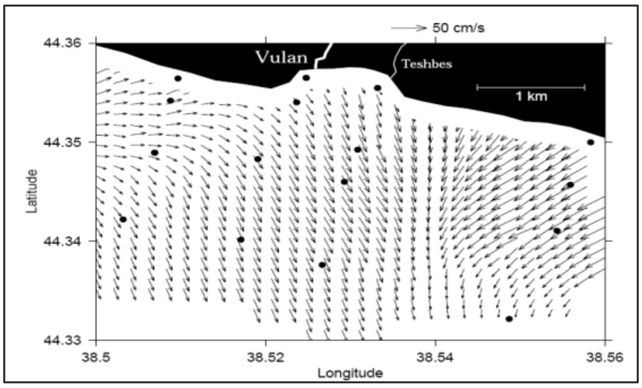
Optical remote sensing from board a ship is of great importance for estimation of water content and admixtures distribution in inland seas and coastal regions of oceans. There have been a lot of works applying spectrophotometry from board a ship since the ninetieth of the last century (as an example, see (1-4)). However, the results of such measurements are strongly affected by wind, cloudiness and sea surface roughness as well as experiment conditions. As a result one need either to restrict dramatically the suitable weather and experiment conditions (for instance, carry on measurements only with the clear sky that is often impossible for some regions) or introduce some calibration method. The latter is the objective of this work.

METHODS

Sea radiance coefficient spectrum Ro(λ), which is one of the most informative characteristics of the sea water, can be obtained with the special spectrophotometer developed for measuring the three values: upward sea surface radiance B_{sea}, radiance of the adjacent sky area B_{sky} (it is the area that contributes most to the reflection part of the sea surface radiance) and radiance of the horizontal white screen B_{ws} (it estimates the total illumination of the sea surface). After subtracting the reflection part from the upward sea surface radiance and dividing the result by the total illumination of the sea surface the sea radiance coefficient spectra is obtained:

$$Ro(\lambda)=(B_{sea} - r\, B_{sky})/B_{ws}$$

The measurements were made from board a moving ship in the north-eastern part of the Black Sea. The obtained sea radiance coefficient spectra for the 16 measurements are shown in Fig. 1.



	SHORE	SHORE	
8	1	9	16
7	2	10	15
6	3	11	14
5	4	12	13

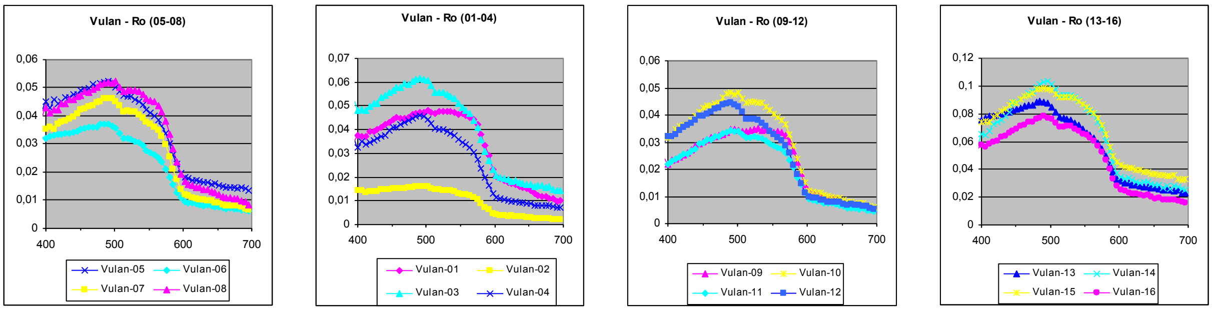
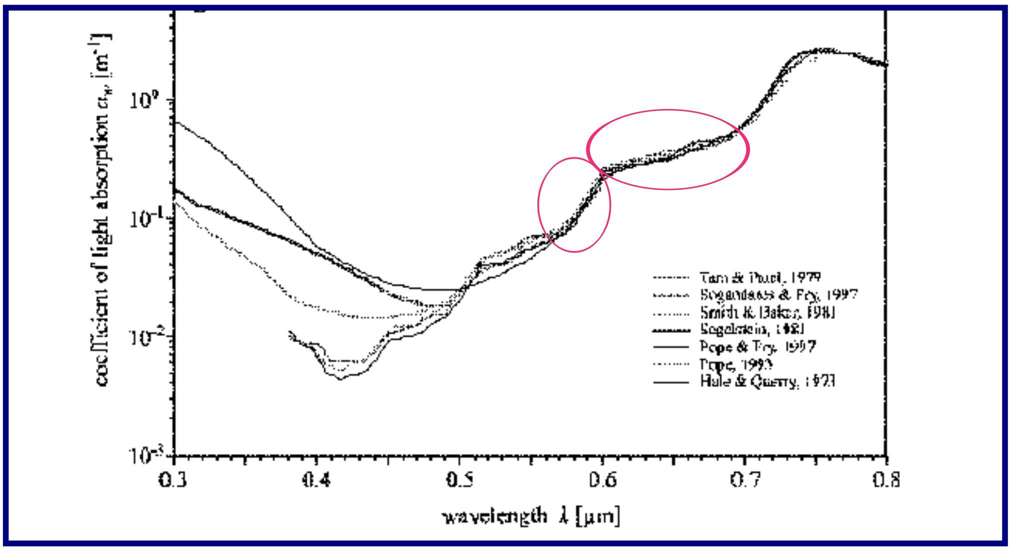


Figure 1: Sea radiance coefficient spectra obtained in the Black Sea at the 16 stations at the Vulan river mouth

Though the main water admixtures concentration changes gradually from the river Vulan mouth to the open sea, one can see that the obtained spectra have rather chaotic appearance. That is the result of fast changes in the conditions of water surface illumination, reflectivity of the wavy surface and difference in radiance of cloudy and non-cloudy sky areas.

However, analyzing these spectra and some other ones obtained by the same method in different aquatoria, their common feature was revealed: regardless of the water content they all have so-called “step” – rapidly falling section of the spectrum from 580nm to 600nm turns into flatter section from 600 nm to 700 nm. Since the main water admixtures absorption and backscattering have no peculiarities in this spectral region, the revealed “step” can be explained only by the peculiarities in pure water absorption spectra (Fig 2).

a)



b)

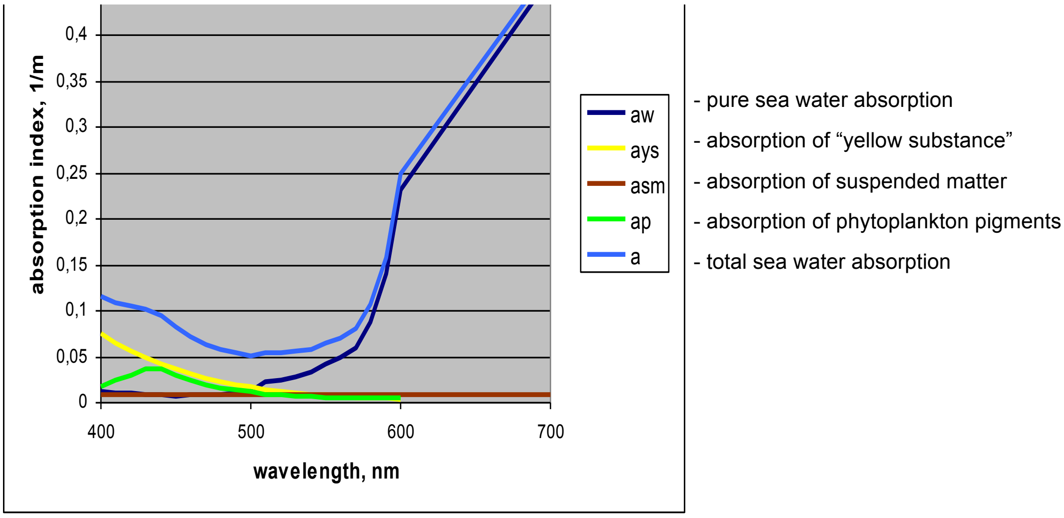


Figure 2: Empirical absorption spectra of liquid water, as determined by various authors (5) (a). An example of light absorption by the natural waters main admixtures and the total spectrum of sea water absorption (b).

This explanation of the “step” appearance in the sea radiance coefficient spectra enable one to understand why practically all such spectra in coastal areas have abovementioned peculiarities. It should be mentioned that in ocean waters such peculiarities also exist, however they are not seen as the signal is negligibly small in the spectral range from more than 600 nm.

The revealed properties of the spectrum enable me to calibrate sea radiance coefficient spectra obtained by measurements. Firstly, it is assumed that the true spectrum is different from the measured one and can be calculated with the help of two values:

$$Ro^* = k\,Ro - delR$$

Here *k* is the coefficient responsible for the total illumination changes and *delR* stands for the discrepancies in the reflectance part of the sea radiance signal.

Secondly, the well-known dependence of the sea radiance coefficient upon the absorption and backscattering indexes of sea water (a and b_b) is taken into account:

$$Ro^{*}= \frac{k_0 \cdot b_b}{a + b_b}.$$

Thirdly, for the spectral band 580nm-:-700nm we assume phytoplankton pigments absorption and “yellow substance” absorption are negligibly small in comparison to the absorption of pure sea water and backscattering is practically constant:

$$a_p, a_{ys} << a_w$$

$$b_b = b_{600} = const$$

That means the absorption at 580nm and 700nm can be written as

$$a_{580} = a_{600} - d_2, \quad a_{700} = a_{600} + d_1$$

Here $d_1 = a_{w700} - a_{w600}$, $d_2 = a_{w600} - a_{w580}$, $a_{600} = a_{w600} + a_s$.

Using all those expressions a system of three equations was derived:

$$\begin{cases} Ro_{600} - Ro_{700} = \dfrac{d_1}{(k/(k_0 b_{600}))(a_{600} + b_{600})(a_{600} + b_{600} + d_1)} \\ Ro_{580} - Ro_{600} = \dfrac{d_2}{(k/(k_0 b_{600}))(a_{600} + b_{600})(a_{600} + b_{600} - d_2)} \\ k/(k_0 b_{600}) Ro_{600} - delR/(k_0 b_{600}) = \dfrac{1}{a_{600} + b_{600}} \end{cases}$$

This is a system of three equations with three unknown variables: $a_{600} + b_{600}$, $k/(k_0 b_{600})$ and $delR/(k_0 b_{600})$. Solving it we can calculate some spectrum of the sea water under investigation in the whole visible (400 nm -:- 700 nm):

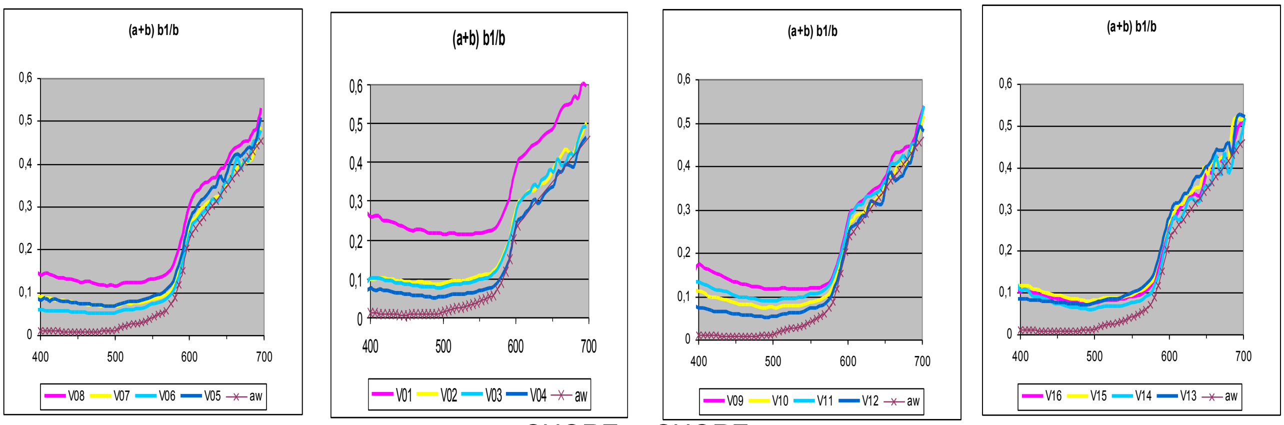
$$\frac{(a + b_b)}{b_b / b_{600}} = \frac{1}{k/(k_0 b_{600}) Ro - delR/(k_0 b_{600})}.$$

It is a rather good estimation of the sea water absorption if backscattering does not differ greatly from b_{600} that is the case in coastal waters.

RESULTS

The suggested method was applied to the above given spectra of the sea radiance coefficient measured in the Black Sea. Comparing the initial spectra and the spectra of water absorption after calibration one can see the positive effect: despite the unfavorable meteorological conditions all the resulting spectra show the decreasing of absorption with increasing distance from the river Vulan mouth (see Fig.3).

The next step was processing the absorption spectra in order to reveal the water content at every point for comparison to the results of water samples analysis. Using the model spectra for specific absorption of the three natural water admixtures (phytoplankton, “yellow substance” and suspended matter) their concentrations were calculated.



	SHORE	SHORE	
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7	2	10	15
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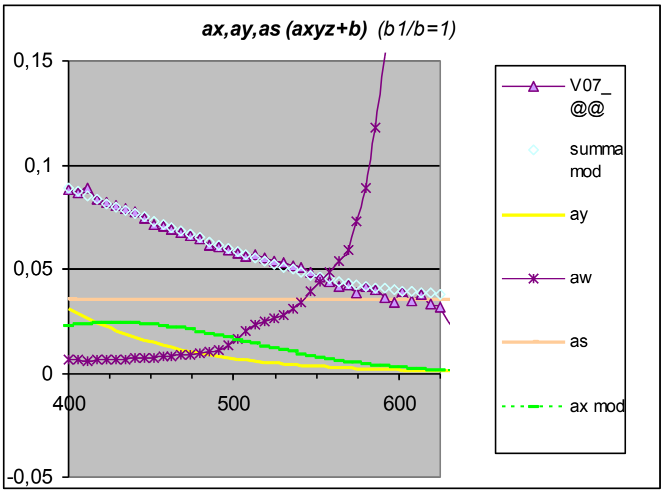
5	4	12	13

Figure 3: Sea water absorption spectra calculated from the measurements of sea radiance coefficient with the help of a new calibration method taking into account some inherent properties of pure seawater absorption.

The illustration of this procedure is given in Fig.4. After subtracting pure water absorption the curve (triangles) represents the joint absorption spectrum of the admixtures. Varying the values of the main admixtures absorption we reach the best coincidence of the experimental and model total absorption curves and thus estimate the admixtures concentrations.

a)



Cp = 0.7 mg/m3
ay = 0.007 1/m ± 30%
as = 0.035 1/m

b)

	SHORE	SHORE	
△ 8	1	9	△ 16
△ 7	△ 2	△ 10	15
6	△ 3	△ 11	14
5	△ 4	12	13

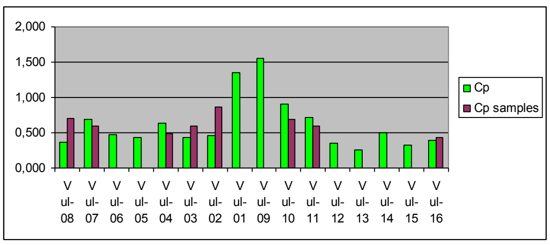


Figure 4: Sea water absorption spectra calculated from the remote measurements of sea radiance coefficient with the help of a new calibration method taking into account some inherent properties of pure seawater absorption. Three natural admixtures concentration values are obtained with the procedure of the model and experiment absorption matching (a). Comparison of pigments concentration estimated remotely and in samples (b).

Coincidence of the thus remotely estimated concentrations and concentrations obtained by water samples analysis is rather satisfactory.

CONCLUSIONS

The suggested calibration method enables to get sea radiance coefficient spectra and water absorption spectra of the aquatorium under investigation for wide range of the weather and measurement conditions. It should be stressed that as this method is based on the inherent pure water properties it can be applied for various aquatoria. The obtained absorption spectra can be successfully processed to estimate concentration of the three natural sea water admixtures – phytoplankton pigments, “yellow substance” and suspended matter. There is a possibility to add some more impurities with their absorption spectra to this list if necessary.

Estimating of natural admixtures concentration from data of optical passive remote sensing of sea surface from board a ship combined with the new calibration enables to get some necessary data during ground truth measurements or explore the sea areas which are too close to the coastal line or are unseen from satellites because of cloudiness.

The future research are planned for further validation of this method with relevant results of water content determination on water samples and for investigation of other coastal and inland seas.

ACKNOWLEDGEMENTS

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