ISSN 1573-160X, *PHYSICAL OCEANOGRAPHY*, VOL. 31, Iss. 1, pp. 3-17 (2024)
Original Russian Text © E. N. Korchemkina, E. V. Mankovskaya, 2024,
published in *Morskoy Gidrofizicheskiy Zhurnal*, 2024, Vol. 40, Iss. 1, pp. 5–20

Original article

Spectral Reflectance Coefficient, Color Characteristics and Relative Transparency of the Black Sea Waters in Spring, 2019 and 2021: Comparative Variability and Empirical Relationships

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Abstract
Purpose. The work is purposed at studying spatial variability of the sea reflectance coefficient using the field data, as well as at obtaining empirical relationships between the colorimetric and bio-optical characteristics and comparing them with the already published data.
Methods and Results. The measurement data on spectral reflectance coefficient of the water column and the Secchi disk depth obtained in the expeditions of the R/V *Professor Vodyanitsky* in the northern and northeastern parts of the Black Sea in April 18 – May 13, 2019 and April 22 – May 8, 2021 were used. Based on the reflectance spectra, the following color characteristics were calculated: dominant wavelength, water color purity, hue angle, and the inherent optical characteristics (absorption of dissolved organic matter and backscattering by suspended particles). Variability of the sea reflectance coefficient and its color characteristics was analyzed for similar periods in spring 2019 and 2021. For the combined data for 2019 and 2021, the relationships between the Secchi disk depth and the reflectance coefficient at maximum, as well as the dominant wavelength were obtained and compared to the known data. For the first time, the empirical relationships connecting the hue angle with the dissolved organic matter absorption and the backscattering by suspended particles were obtained to calculate the inherent optical characteristics of the Black Sea waters.
Conclusions. The distribution of the reflectance coefficient observed in 2019 is more typical of late spring, whereas the similar distribution observed in 2021 rather indicates the continuing winter-spring development of phytoplankton communities that is typical of the deep part of the Black Sea waters in the years with cold winters. Significant correlations between the colorimetric and bio-optical parameters of seawater were established. They can be used as a part of the empirical and semi-analytical algorithms for comprehensive assessing (including application of remote sensing data) the hydrooptical characteristics of the Black Sea waters.

Keywords: spectral reflectance coefficient, Secchi disk depth, dominant wavelength, color purity, hue angle, chromaticity diagram, absorption by dissolved organic matter, particles backscattering, Secchi disk, ocean color

Acknowledgements: The work was carried out within the framework of a state assignment on topics No. FNNN-2024-0016 and No. FNNN-2024-0012, the data were obtained in the 106th and 116th cruises of the R/V *Professor Vodyanitsky* (Center for Collective Use “R/V *Professor Vodyanitsky*” of the Federal State Budgetary Scientific Institution of Federal Research Center “A. O. Kovalevsky Institute of Biology of the Southern Seas of RAS”).

For citation: Korchemkina, E.N. and Mankovskaya, E.V., 2024. Spectral Reflectance Coefficient, Color Characteristics and Relative Transparency of the Black Sea Waters in Spring, 2019 and 2021: Comparative Variability and Empirical Relationships. *Physical Oceanography*, 31(1), pp. 3-17.

Introduction

Marine Hydrophysical Institute of RAS has accumulated and is constantly expanding an array of data from measurements of seawater optical parameters, such as spectral reflectance coefficient of the water column, beam attenuation coefficient, Secchi disk depth (relative transparency), etc. The analysis of these data provides a good opportunity to study, first of all, the variability of spectral reflectance coefficient, which is the main parameter measured both by contact methods and remotely, as well as color characteristics of water and relationships with other bio-optical parameters.

Various areas of the World Ocean differ in the visible color of waters, which can vary from deep blue to almost brown. The color change is due to the content of impurities of various origins in the water. The spectral reflectance coefficient spectrum and its shape contain information about the color characteristics of water.

The first oceanologic characteristic of water color was the Forel–Ule scale [1] with different color numbers of test tubes. The result of using this color scale can be somewhat subjective since the color is determined visually. To objectively assess the water color, we use the parameters that represent color in mathematical form based on the three-component theory of human color vision: color coordinates and hue angle, dominant wavelength and color purity [2] [1, 2].

This work presents measurement data of spectral reflectance coefficient (*R*rs) of the water column and the Secchi disk depth obtained in 2019 and 2021 during the expeditions to the northern and northeastern parts of the Black Sea. The purpose of this work is to analyze the reflectance coefficient spatial variability based on field data, as well as to obtain empirical relationships between color and bio-optical characteristics and compare them with literature data. The work is to some extent a continuation of our paper [3], since in 2021 new contact optical measurement data were obtained in the same area of the sea and during the same period of the year. That let us carry out a comparative analysis of variability of reflectance coefficient and color characteristics of the Black Sea waters, as well as establish new empirical dependencies and clarify those previously obtained.

The use of empirical formulas for the relationship between the studied parameters is a simple way of modeling in the case where the physical nature of the relationship is not important. Empirical relationships between hydro-optical characteristics are regional and seasonal in nature and provide satisfactory results with the correct choice of conditions and variability ranges of the studied parameters. Since color characteristics of seawater are easy to determine, the relationships between them and bio-optical parameters have been used for a long time [3]. They are applied as part of empirical and semi-analytical algorithms [4] for a comprehensive assessment of seawater hydro-optical characteristics. Considering certain corrections [5], color characteristics can be calculated from satellite measurements which expands their scope of application.

Materials and methods

This paper examines measurement data of spectral reflectance coefficient (*R*rs) of the water column and the Secchi disk depth obtained during R/V *Professor*

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[1] Jerlov, N.G., 1976. *Marine Optics*. Amsterdam: Elsevier, 230 p.

[2] Shifrin, K.S., 1983. [Secchi Disc Depth and the Sea Color]. In: *Introduction to Ocean Optics*. Leningrad: Gidrometeoizdat, pp. 23-30 (in Russian).

[3] Mankovsky, V.I., Solov’iev, M.V. and Mankovskaya, E.V., 2009. [*Hydrooptical Properties of the Black Sea. Handbook*]. Sevastopol: MHI NAS of Ukraine, pp. 40-41 (in Russian).

Vodyanitsky expeditions in spring 2019 and 2021 in the Black Sea. The survey was carried out in the Black Sea northern and northeastern parts (42.5°–45.8°N; 31.5°–39.8°E) from 18 April 2019 to 13 May 2019 (106th cruise) and from 22 April 2021 to 8 May 2021 (116th cruise). The spectral reflectance coefficient measurements were carried out from the vessel with a spectrophotometer developed in the Marine Optics and Biophysics Department of Marine Hydrophysical Institute of RAS [6]. The Secchi disk depth (relative transparency) was determined using a standard technique [4].

Based on the measured reflectance coefficient spectra, the following color characteristics were calculated: dominant wavelength in the sea radiance spectrum, water color purity and hue angle.

A quantitative assessment of the water color is a dominant wavelength λ_{dom} in the sea radiance spectrum [2]. It is based on the colorimetric system *X*, *Y*, *Z* (Fig. 1), where the *x*, *y*, *z* chromaticity coordinates are calculated using the following formulas:

$$X = \int_{400}^{700} R_{\mathrm{rs}}(\lambda)\bar{x}(\lambda)d\lambda; \quad x = X/(X+Y+Z);$$

$$Y = \int_{400}^{700} R_{\mathrm{rs}}(\lambda)\bar{y}(\lambda)d\lambda; \quad y = Y/(X+Y+Z);$$

$$Z = \int_{400}^{700} R_{\mathrm{rs}}(\lambda)\bar{z}(\lambda)d\lambda; \quad z = Z/(X+Y+Z);$$

where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are functions of spectral sensitivity of the human eye. λ_{dom} value is equal to the wavelength of monochromatic light (called dominant), which must be mixed in a certain proportion with the white light to obtain visible color of the sea (Fig. 1).

Water color purity *P* is the proportion (percentage) where monochromatic light (dominant wavelength) must be mixed with white light to produce visible color of the sea. The water color purity is related to its transparency: highly transparent waters are characterized by high color purity, while in turbid waters the color purity is low [3]. The value of *P* is determined by the ratio of two collinear distances $P = E\lambda_d/EA$ (Fig. 1, *bottom*).

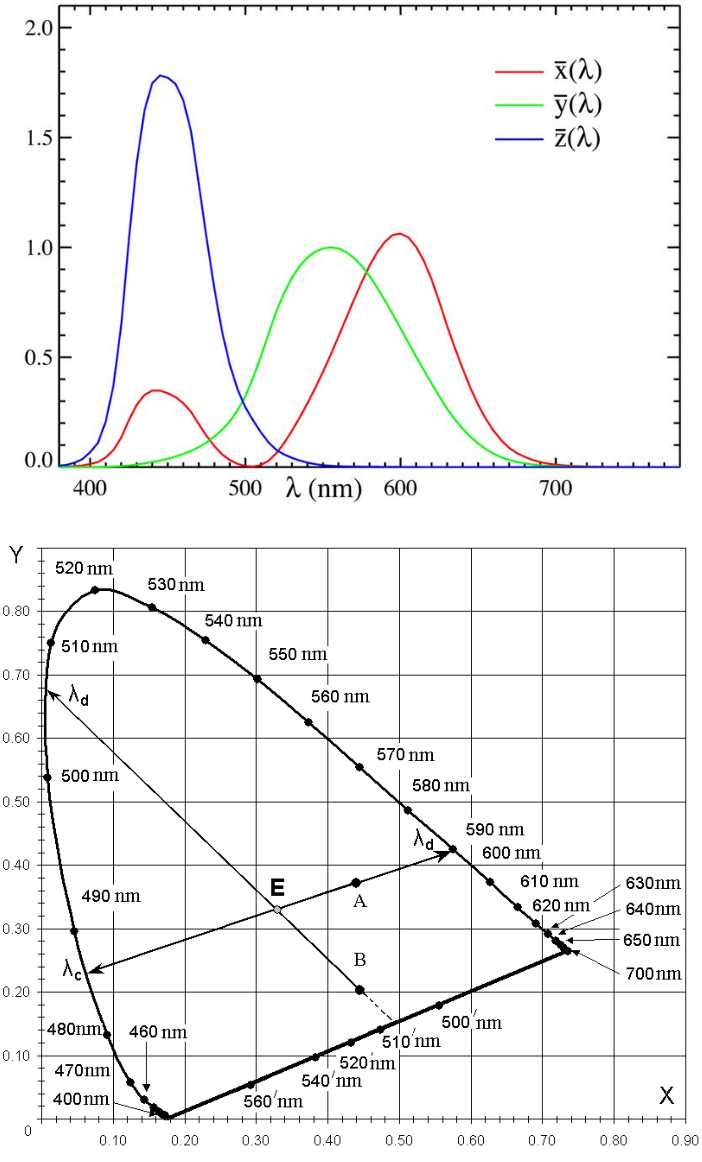
For any given point (*x*, *y*) on the chromaticity diagram, the value of hue angle α is defined as the value of the angle (in degrees) between the segment connecting the "white point" with the given point (*x*, *y*) and *X* axis [2]. That is, the hue angle α (in degrees) is determined by the following expression:

$$\alpha = (180/\pi)(\mathrm{arctg}((y - y_{\mathrm{w}})/(x - x_{\mathrm{w}}))\mathrm{mod}\, 2\pi,$$

where $x_{\mathrm{w}} = y_{\mathrm{w}} = 1/3$ are coordinates of the white point on the chromaticity diagram (Fig. 1, *bottom*). Blue-green and blue colors correspond to the hue angles

[4] SOI, 1977. [Determination of the Relative Transparency and Colour of Sea Water]. In: A. N. Ovsyannikov, N. T. Filatov and I. F. Kirillov, eds., 1977. [*Guide to Hydrological Work in the Oceans and Seas*]. Leningrad: Gidrometeoizdat, pp. 299-303 (in Russian).

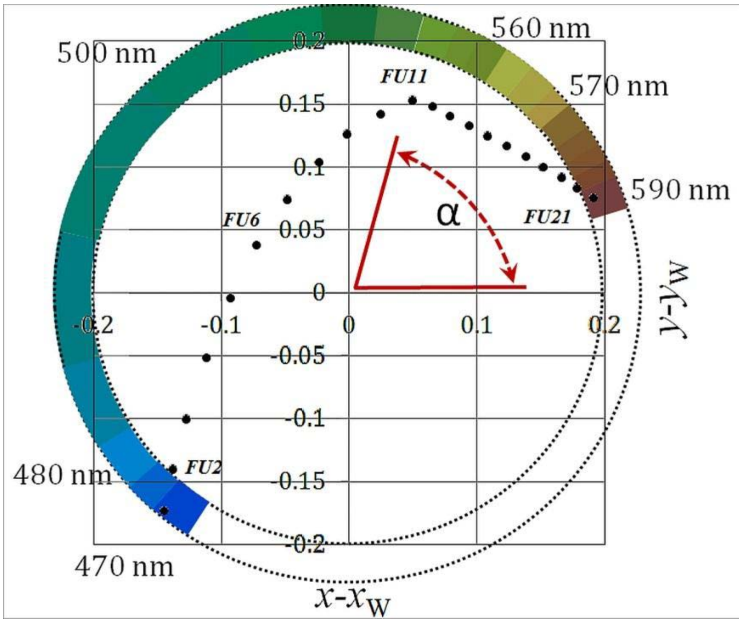
exceeding 180°. The hue angle decreases with the shift of the dominant wavelength towards the long-wavelength region (Fig. 2).



F i g. 1. Spectral sensitivity functions for a standard observer according to *CIE* 1931 [5] [1] (*top*); color triangle in *x*, *y* coordinates [6] (*bottom*): point *E* is the white color; points A and *B* are some arbitrary colors; λ_d is the position of dominant wavelength

[5] Wikimedia Commons. *File: CIExy1931.png.* [online] Available at: https://upload.wikimedia.org/wikipedia/commons/8/87/CIE1931_XYZCMF.png [Accessed: 23 January 2023].

[6] Larionova, E.V., 2013. [*Physical Foundations of Color*]. St. Petersburg, 113 p. (in Russian).



F i g. 2. Chromaticity diagram showing the correspondence of color hue angle α to the white point (x_w, y_w) of the *FU* scale colors. The dominant wavelength of the specific segment is indicated in nm [2, p. 25667]

We calculate the absorption by dissolved organic matter and suspended particles backscattering using a semi-analytical algorithm [6], where the spectrum of reflectance coefficient has the following form:

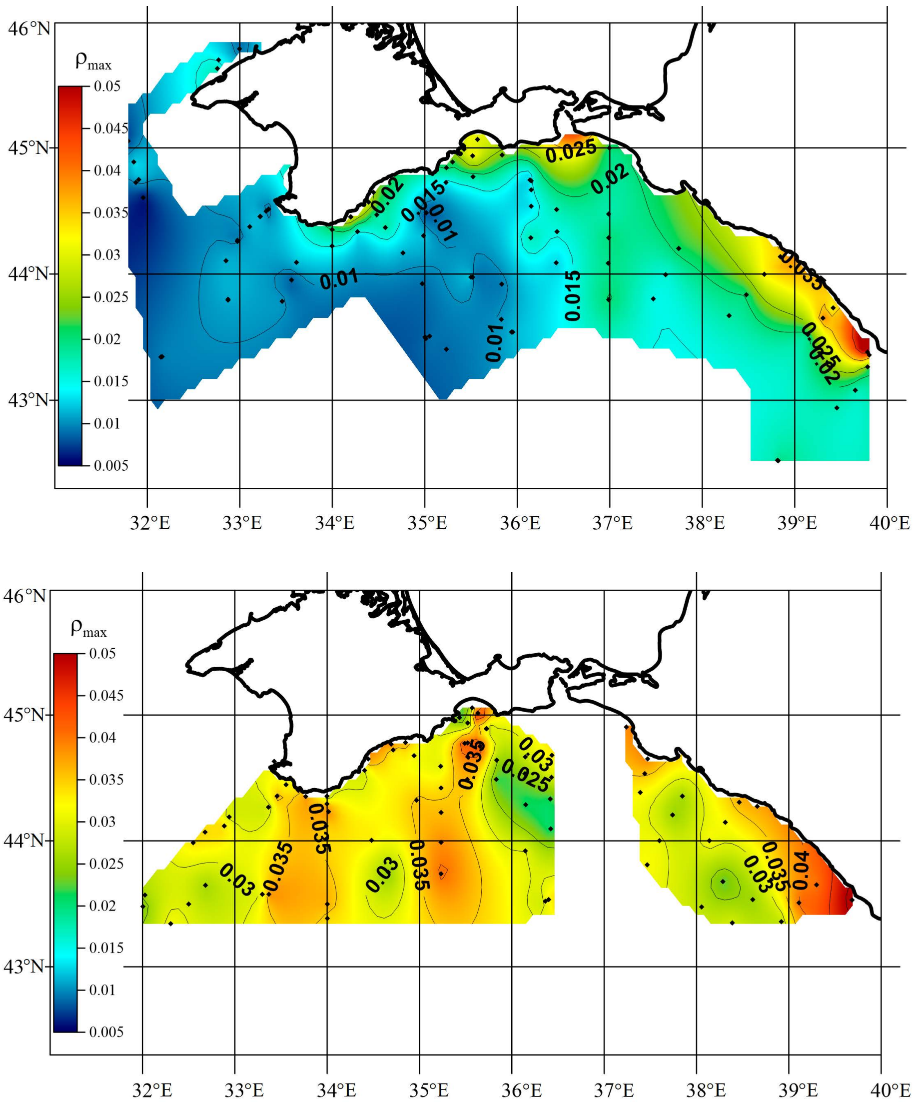
$$R_{rs}(\lambda) = k\frac{b_{bw}(\lambda) + b_{bp}(550)\left(550/\lambda\right)^{\nu}}{a_w(\lambda) + C_{ph}a^*_{ph}(\lambda) + a_{org}(440)\,e^{-S(\lambda-440)}},$$

where $k = 0.15$; $b_{bw}(\lambda)$ is pure water backscattering [7]; $a_w(\lambda)$ is absorption by pure water [8]; $a^*_{ph}(\lambda)$ is a spectrum of specific absorption by phytoplankton pigments (normalized to the chlorophyll a concentration) [9]; ν = 1 is a backscattering spectral slope dependent on particle size [7]; S = 0.018 is a spectral slope of absorption by dissolved organic matter [10]; $b_{bp}(550)$ is suspended particle backscattering at 550 nm; C_{ph} is a concentration of phytoplankton pigments and $a_{org}(440)$ is absorption by dissolved organic matter at 440 nm.

Comparative variability of reflectance coefficient and color characteristics

Optical expeditionary measurements were carried out for similar spring periods of 2019 and 2021 which makes it possible to analyze variability of reflectance coefficient and seawater color characteristics.

[7] Monin, A.S., ed., 1983. *Optics of the Ocean*: *[In 2 Volumes]*. Moscow: Nauka (in Russian).



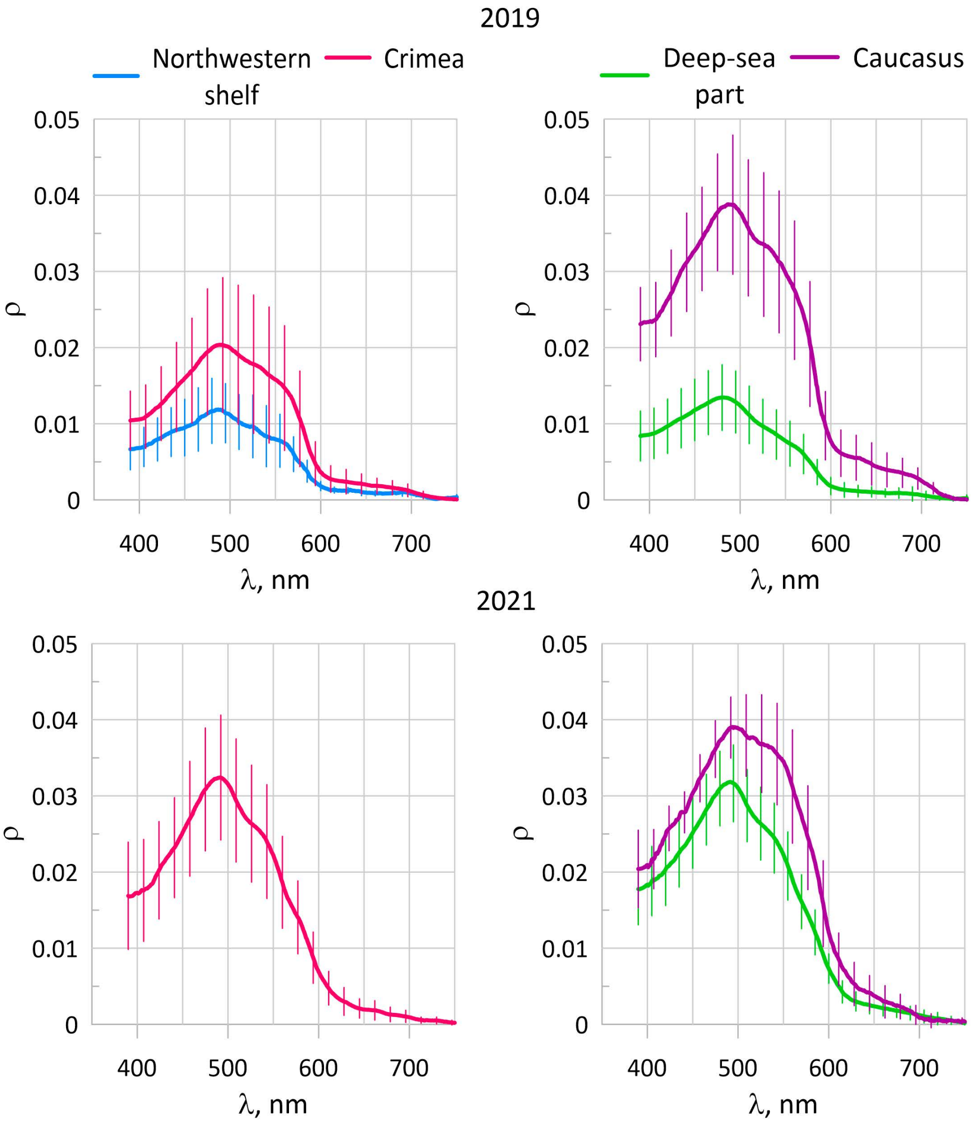
F i g. 3. Distribution of the reflectance coefficient spectral maxima: *a* – in 2019; *b* – in 2021. Black dots show the stations where reflectance measurements were taken

In 2019, the spectra of the water column reflectance coefficient were obtained at 89 stations, in 2021 – at 68. The distribution of the reflectance coefficient spectral maxima according to the expeditionary data is given in Fig. 3. Four regions in the area under study were identified for further analysis:

1) northwestern shelf (only in 2019);
2) coastal zone of Crimea with depths of up to 200 m;
3) coastal zone of the Caucasus with depths of up to 1000 m;
4) central deep-sea part.

It should be noted that the division into regions was carried out differently than in paper [3]. Near the Caucasian coast, the shelf zone with depths of up to 200 m extends 5–6 km off the coast and river plumes propagate beyond it. Therefore, 1000 m isobath that is located, on average, 15 km off the coast was chosen as the coastal zone boundary. In the previous paper, the “eastern part” was different (the area east of 37°E). In the present paper, part of this area was included in the “central deep-sea part.”

The average reflectance coefficient spectra for the selected areas are presented in Fig. 4. The measured and calculated optical characteristics of seawater, averaged over a set of stations in the corresponding region, are given in the Table.



F i g. 4. *R*rs spectra averaged over the regions and their standard deviation (shown by shading) based on the measurement data obtained in 2019 and 2021

Secchi disk depth (Z_d, m), *R*rs and its characteristics

Region	Z_d, m	ρ_{max}	λ_{max}, nm	λ_{dom}, nm	*P*, %	α, °
2019						
Northwestern shelf	12 ± 3	0.012 ± 0.004	485 ± 9	489 ± 2	38 ± 3	192 ± 7
Coastal zone of Crimea	8 ± 3	0.021 ± 0.009	491 ± 6	491 ± 4	35 ± 7	192 ± 16
Central deep-sea part	13 ± 4	0.014 ± 0.004	482 ± 7	485 ± 2	45 ± 6	203 ± 9
Coastal zone of the Caucasus	6 ± 2	0.039 ± 0.009	486 ± 6	489 ± 3	35 ± 7	185 ± 10
2021						
Coastal zone of Crimea	8 ± 2	0.032 ± 0.008	492 ± 5	490 ± 2	36 ± 6	187 ± 7
Central deep-sea part	7 ± 1	0.032 ± 0.005	491 ± 6	490 ± 2	36 ± 4	187 ± 8
Coastal zone of the Caucasus	4 ± 1	0.040 ± 0.005	503 ± 12	495 ± 6	26 ± 7	155 ± 20

N o t e: ρ_{max} is the *R*rs spectral maximum; λ_{max} is the corresponding wavelength (nm); λ_{dom} is the dominant wavelength (nm); *P* is color purity (%); α is hue angle (°). The region-averaged values are given, ± standard deviations over the whole ensemble of measurements.

The *R*rs in 2019 varies significantly: from 0.005...0.01 (at the spectral maximum) in the area of the northwestern shelf and in the central deep-sea part to 0.03...0.05 in the coastal zones of Crimea and the Caucasus (Fig. 4). The shape of all *R*rs spectra is characteristic of the Black Sea waters. Small differences are observed where the *R*rs maximum is located. It is situated in the vicinity of 480 nm in the central deep-sea part and at the northwestern shelf and in the vicinity of 490 nm in the coastal zone of Crimea. The *R*rs spectrum shape is different for waters in the Sochi region, where a plume was recorded due to the Mzymta River runoff. Here, the *R*rs spectrum maximum is shifted towards long waves up to 497 nm.

In 2021, the *R*rs values varied slightly throughout the entire study area. There was practically no difference between the deep-sea and coastal parts both in the spectra shape and in the *R*rs values. The exception was the *R*rs values in the Feodosia Bay area. The spread of maximum values was observed from 0.05 in the bay to 0.02 at the shelf outside the bay. Along the Caucasian coast, we also recorded the highest *R*rs values which were due to river runoff, a known source of suspended matter. In general, the *R*rs values in 2021 were higher than in 2019.

Observations of the Secchi disk depth Z_d were performed for 69 stations in 2019 and for 48 stations in 2021. In 2019, the observed spread of values ranged from 4 m in the plume near the Caucasus coast to 23 m in the deep-sea part of the Black Sea. In 2021, the spread ranged from 5 to 12 m both in the deep-sea part and in the coastal zone of Crimea, which corresponds to the observed low variability of *R*rs.

According to all measurements of reflectance coefficient spectra, the variability range of the dominant wavelength values in 2019 was 482-496 nm. According to the chromaticity diagram (see Fig. 2), the color is characterized as blue in the wavelength range of 480-490 nm and blue-green in the range of 490-500 nm. The color shift towards longer wavelengths is estimated to correspond to an increase in the organic matter content in the water.

In 2019, estimated color purity values ranged from 24 to 56%. Low values, i.e., more turbid waters, were observed in the plume near Sochi, near Yalta and Feodosia, as well as in the area of 33°E, 44°N. At these stations, the waters had a more greenish tint than the waters of the rest of the test site according to visual assessments. High color purity values were obtained for the eastern part of the deep-sea region.

In 2021, the variability range of the dominant wavelength values was 486-509 nm. Waters with a greenish tint were observed in the coastal zone off the Caucasus coast, where low color purity values (P = 13%) were also recorded. High values (up to 47%), as in 2019, were noted in the deep-water part.

The meteorological data analysis revealed that weather conditions in 2019 were warmer (air temperature averaged ~ 2°C higher and was above 0°C in January – March) and there was less precipitation than in 2021. The differences in climate conditions affected formation features of the fields of hydro-optical characteristics. The pattern of *R*rs distribution differs despite the same calendar periods for carrying out optical measurements. In 2019, the observed *R*rs distribution was more typical of the spring period, while in 2021 it was more typical of the local climatic winter. This situation is confirmed by the distributions of chlorophyll a and the total suspended matter concentrations obtained from expeditionary measurements. According to biological determinations, chlorophyll a concentrations were on average 2–4 times higher in 2021, which indicates the ongoing winter-spring development of phytoplankton communities. This feature of phytoplankton seasonal dynamics is inherent in the open waters of the Black Sea and is usually observed from January to March [11, 12]. Moreover, the amount of biomass and the duration of phytoplankton development are higher in the years with cold winters than in the years with warm winters [11].

Empirical relationships between color characteristics of reflectance coefficient

Previously, we obtained empirical relationships for the Secchi disk depth, the *R*rs spectral maximum and the dominant wavelength in our work [3]. The new field data obtained in 2021 make it possible to clarify these relationships, since the measurements were made with the same instrument using the same methodology in similar areas and during the same periods of the year.

For the entire data array for 2019 and 2021, the relation equations for the Secchi disk depth Z_d and the reflectance coefficient values at the maximum ρ_{max} and the dominant wavelength λ_{dom} have the following form (Fig. 5):

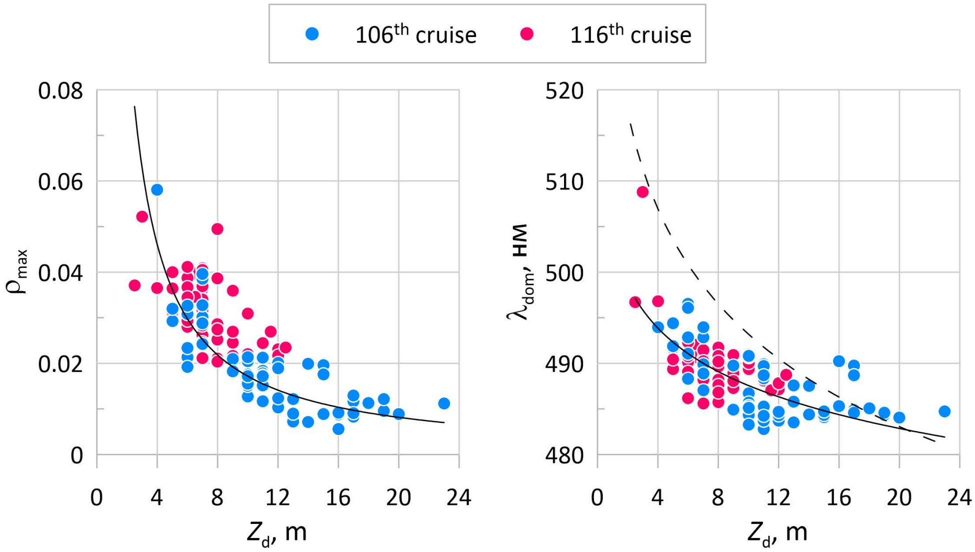
$$\ln\rho_{\mathrm{max}} = -1.08\ln Z_{\mathrm{d}} - 1.59; R = 0.82,$$

$$\ln\lambda_{\mathrm{dom}} = -0.014\ln Z_{\mathrm{d}} + 6.22; R = 0.73.$$

In [13], based on measurements taken in the waters of the tropical Atlantic Ocean, the formula of $\lambda_{dom} = f(Z_d)$ relationship was obtained for Z_d values within the range of 10–41 m:

$$\ln\lambda_{\mathrm{dom}} = -0.032\ln Z_{\mathrm{d}} + 6.27; R = 0.99.$$

The corresponding relationship is shown by the dashed line in Fig. 5, *right*. This formula in [13] is recommended to be used when estimating λ_{dom} in various waters for Z_d values in the range of 5–41 m. However, according to the considered data from contact measurements in 2019 and 2021, there is a difference between the empirical relationships proposed in [13] and the ones we obtained. The divergence of the curves is explained by different concentrations of small particles (radii less than 1 μm) in the suspension in the Black Sea and in the tropical Atlantic Ocean waters. According to work [14], the higher the concentration of fine suspended matter, the lower the Secchi disk depth under equal conditions of sea illumination and the light attenuation by water. According to guidebook [3] and work [15], the concentration of fine particles in the Black Sea is 5–6 times higher than in the tropical Atlantic Ocean waters, and accordingly the Z_d values are lower.



F i g. 5. Relationship between the Secchi disk depth and the reflectance coefficient spectral maximum (*left*) as well as the dominant wavelength (*right*). Solid line is the approximation of the contact measurements in 2019 and 2021, dashed line is the relation equation from [13]

The intersection of the curves $\lambda_{dom} = f(Z_d)$ at Z_d = 20 m (Fig. 5, *right*) can be explained as follows. The concentration of fine suspended matter in the sea decreases from coastal areas, where it reaches its maximum, to central regions due to gradual deposition of fine suspended matter. In areas with Z_d = 20 m, the concentration of fine suspended matter was the same as in the waters of the tropical Atlantic Ocean.

Between the values of the Secchi disk depth Z_d and the color purity P (Fig. 6, *left*) a direct correlation takes place:

$$\ln P = 0.42 \ln Z_d - 1.89; R = 0.79.$$

An inverse relationship is observed between color purity P and the dominant wavelength λ_{dom} (Fig. 6, *right*). The corresponding relation equation is:

$$\ln P = 0.04 - 26.02 \ln\left(\frac{\lambda_d}{531}\right); R = 0.91.$$

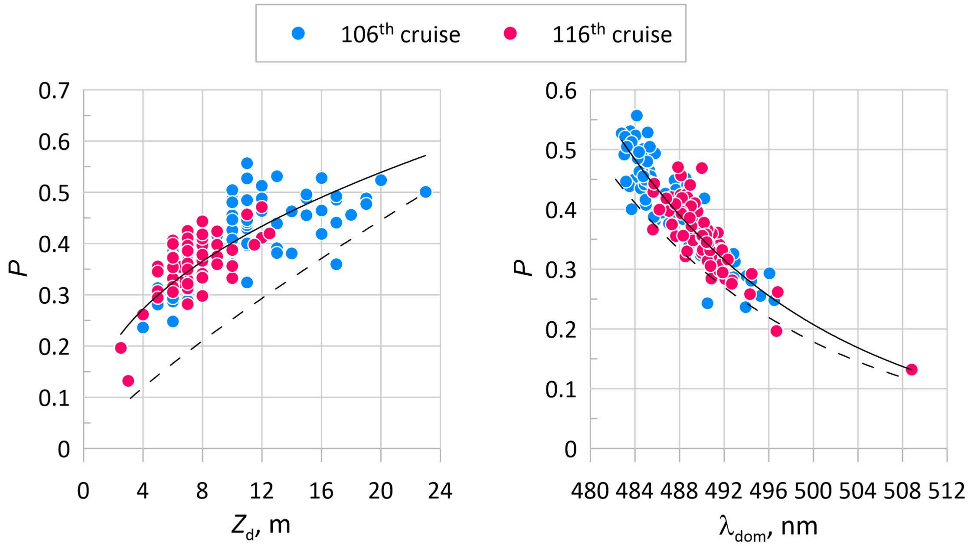
In [13], the relationship between the water color purity and the relative transparency $P = f(Z_d)$ based on reflectance spectra measurements of the tropical

Atlantic Ocean waters (Z_d = 10...41 m) and in the Black Sea (Z_d = 3...16 m) is expressed by the formula:

$$\ln P = 0.82\ln Z_d + 1.34; R = 0.98,$$

and the relationship between color purity and the dominant wavelength is expressed by the formula:

$$\ln P = 1.34 - 25.63\ln(\lambda_d/531).$$



F i g. 6. Relationship between the color purity and the Secchi disk depth (*left*) as well as the dominant wavelength (*right*). Solid line is the approximation of the contact measurements in 2019 and 2021, dashed line is the relation equation from [13]

For the Atlantic Ocean waters, the values of Secchi disk depth Z_d exceeding 10 m and the corresponding part of the relation line $P = f(Z_d)$ from [13] indicated by the dashed line (Fig. 6, *left*) approaches the dependence obtained in our study. Within the range of the Secchi disk depth values 3–23 m observed according to the measurement data in 2019 and 2021, the relation line from [13] lies lower than what we obtained. The difference is due to the fact that the relationship formula in [13] was obtained mainly from *R*rs measurements in the Atlantic Ocean and for the Black Sea waters less than ten values from [16, p. 66] were applied. This is also explained by different ratio of large suspended organic particles and small particles of mainly mineral origin in the water. Thus, at the same Secchi disk depth Z_d color purity values may differ and vice versa. For example, in our study the water color purity varied from P = 13% at Z_d = 3 m to P = 50% at Z_d = 23 m. We observed cases when the color purity values were slightly higher (55%), but at the same time the relative transparency was smaller (Z_d = 10...13 m).

The graph in Fig. 6, *left* clearly shows the difference between the location of sets of points for two expeditions. In 2021 (red dots), the concentration of suspended organic particles is higher than in 2019 (blue dots) due to the ongoing winter-spring phytoplankton development, which is reflected in the color purity values – they are lower. If the data on the composition and abundance of phytoplankton community is available, this type of relationship $P = f(Z_d)$ can presumably be used to assess bio-optical state of the Black Sea waters.

In the Black Sea, the seawater color is determined mainly by dissolved and suspended organic matter; an increase in the light absorption by organic matter in the short-wavelength region of the spectrum leads to the *R*rs maximum shift and, as a result, the dominant wavelength shift towards long waves. The hue angle is some function of the dominant wavelength and is therefore related to absorption by organic matter.

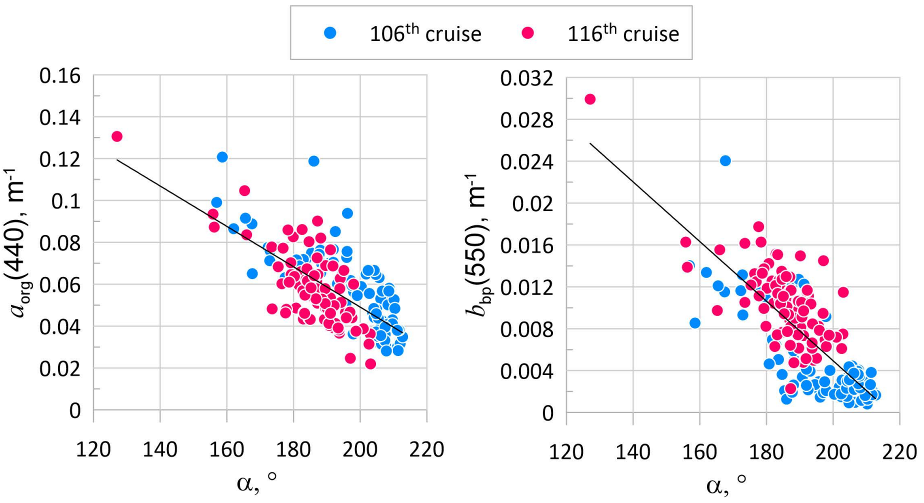
In [17], a relationship between the absorption by dissolved organic matter α_{org} and the hue angle α is obtained. It is a polynomial of degree 3:

$$\log\left(\alpha_{org}(440)\right) = -7.406 \cdot 10^{-7}\alpha^3 + 2.999 \cdot 10^{-4}\alpha^2 - 0.04493\alpha + 1.984; R = 0.96.$$

The equation was obtained for various waters of the World Ocean for a wide range of hue angle variability from 50° to 225°. It can also be used for type 2 waters (in accordance with the classification of A. Morel and L. Prieur [18]) with high content of dissolved organic matter and suspended matter. The hue angle value is determined from the remotely measured sea reflectance coefficient *R*rs.

The field data in our study have much smaller spread of the hue angle values from 150° to 215° (with the exception of one point where the hue angle is 127°). Therefore, the correlation between α_{org} and α values is less significant and the approximation of their dependence by a polynomial, as in [18], does not differ significantly from the linear one (Fig. 7, *left*) and has the following form:

$$\alpha_{org}(440) = -0.001\alpha + 0.243; R = 0.70.$$



F i g. 7. Relationship between the hue angle and the absorption by dissolved organic matter (*left*) as well as the suspended particles backscattering (*right*)

There is also a correlation between the backscattering of suspended particles and the hue angle. It can be explained by several causes. Firstly, suspended organic matter not only absorbs, but also scatters light, i.e., the waters rich in organic matter will have a higher suspended matter backscattering. In addition, coastal waters may contain increased amounts of dissolved organic matter and suspended minerals due to runoff from the land.

The approximation of relationship between backscattering by suspended particles b_{bp} and the hue angle α in the Black Sea waters is also presented in the form of a linear relationship (Fig. 7, *right*):

$$b_{\mathrm{bp}}(550) = -2.8 \cdot 10^{-4}\alpha + 0.062; R = 0.77.$$

These empirical relationships can be used to calculate inherent optical characteristics in the Black Sea waters: absorption by dissolved organic matter and backscattering by suspended particles. In turn, the hue angle values can be calculated from optical data of the sea remote sensing if the data from contact measurements of the spectral reflectance coefficient are absent.

Conclusion

The measurement data of spectral reflectance coefficient of the water column and the Secchi disk depth obtained during the expeditions in the northern and northeastern parts of the Black Sea from 18 April 2019 to 13 May 2019 and from 22 April 2021 to 08 May 2021 were considered. The analysis of the reflectance coefficient variability and its color characteristics for similar spring periods of 2019 and 2021 revealed the following. All *R*rs spectra had a similar shape characteristic of the Black Sea waters. In 2019, high *R*rs variability was observed. The lowest values were recorded at the northwestern shelf and in the central deep-sea part of the test site. The increased values were observed in the coastal zones of Crimea and the Caucasus. In 2021, *R*rs variability in the area under study was relatively low. There was practically no difference in values between the deep-sea and coastal parts. In general, the *R*rs values and its color characteristics in 2021 were higher than in 2019. The values of the seawater color characteristics corresponded mainly to the blue-green color on the chromaticity diagram.

The previous weather conditions in 2019 were warmer and there was less precipitation than in 2021. In 2019, more typical distribution for the second half of spring was observed, while in 2021 the observed distribution indicated a continuing winter-spring development of phytoplankton communities, which was typical for the deep-sea part of the Black Sea in the years with cold winters.

Significant empirical relationships have been established between the Secchi disk depth and the spectral maximum of the reflectance coefficient, the dominant wavelength and color purity. A close correlation is observed between color purity and dominant wavelength. The obtained empirical relationships make it possible to classify *R*rs spectra and simplify such approaches as, for example, cluster analysis.

To calculate inherent optical characteristics in the Black Sea waters, empirical relationships between the hue angle and the absorption by dissolved organic matter and backscattering by suspended particles have been obtained for the first time. The hue angle values can be calculated from the remote sensing data of the sea reflectance coefficient if contact measurement data are not available. In the future, it is planned to calculate the hue angle from satellite data using a regional atmospheric correction algorithm for the Black Sea and compare it with the hue angle values obtained in this work from contact measurements of spectral *R*rs.

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Submitted 24.03.2023; approved after review 04.05.2023;
accepted for publication 15.11.2023.

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The authors have read and approved the final manuscript.
The authors declare that they have no conflict of interest.