Characteristic vertical distribution of extinction coefficient in the upper layer of the deep part of Black Sea

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Seven characteristics optimally describing the vertical distribution of the extinction coefficient in the upper layer of the deep part of Black Sea are proposed. These characteristics well represent the relation of the distribution to the hydrological, chemical, and biological processes. Statistical estimates and maps of horizontal distribution of these characteristics for a many-year period of the stable state of hydrooptical situation in the Black Sea are presented.

The primary hydrooptical characteristic – extinction coefficient (EC, ε) in water – is one of the most informative oceanological characteristics. The EC structure is largely determined by the content of suspended matter (organic and mineral) in water and by the dissolved organic matter, whose distribution, in its turn, depends on various hydrophysical, hydrochemical, and hydrobiological processes in the seawater.

Specific conditions for the formation of hydrological, chemical, and optical structure of water in the Black Sea that are caused by weak water exchange between deep and surface layers and stable cyclonic current system determine its rather a stable vertical structure.[1] Therefore, selection of EC characteristics that optimally describe the EC vertical distribution in the upper layer of the deep part of the sea is of particular importance.

Materials of instrumental EC observations that exist since the early 1960's were odd and hard-to-compare until recently, because they were obtained episodically in different sea regions with different versions of transparency meters and processing methods.[1–4] This prevented efficient use of advantages of hydrooptical investigations (bulky information obtained in real time, connection of transparency distributions with various processes in seawater, and others) and generalization of data for mapping the EC distributions over the whole water area of the deep sea part.

Based on the analysis of long-term instrumental observations of water transparency in the 1960's and 1970's, Neuimin[1] has for the first time separated and described four optical structure layers corresponding to layers with certain hydrological, chemical, and biological properties. They are the surface turbid layer located in the euphotic zone (from the sea surface to the depth of 60–80 m), the intermediate layer of most transparent water near the bottom of the cold intermediate layer (80–130 m), the boundary turbid layer at the interface between the oxygen and hydrogen-sulfide zones (120–200 m), and the deep layer covering the hydrogen-sulfide zone (deeper than 200 m). The results of these investigations, complemented with new data on the optical structure of water and regularities of its formation that appeared in the period until mid-1980's, have been refined, extended, and generalized in Ref. 2.

It was for the first time that a minimum, in the number of EC characteristics, set optimally representing the peculiarities of its vertical distribution and connected with hydrological, chemical, biological, and dynamic characteristics of water that form this distribution in the deep part of the Black Sea was proposed at the conference in Sevastopol in 1986.[5] The maps of horizontal distributions of some of these parameters over the whole deep part of the sea were presented at this conference as well. These maps were drawn based on the averaged many-year data of optical observations.

Below we justify the selection of these characteristics and briefly describe them.

1. ε_0, m^{-1} – EC at the depth of 10 m. At this depth, formation of the transparency field is almost insensitive to small-scale density inhomogeneities caused by daily heating of surface water in summer at calm weather. At this depth, the influence of the vessel body destroying the EC stratification in the surface sea level and inevitable pollutants from the vessel is weak. The EC value at this horizon is largely determined by the concentration of phytoplankton and products of its vital functions. The selection of the EC value at the horizon of 10 m is also connected with the feasibility to qualitatively relate it to the visually observed optical properties of water in the surface ocean layer, namely, the relative transparency and sea color by the standard color scale.

2. $\varepsilon_{\min}$, m^{-1} – the minimum EC value at the vertical profile. Usually, it is the layer with increased transparency, which lies below the bottom of the cold intermediate layer (CIL) and is observed all over the sea. The low EC values in this layer are explained by the fact that CIL is mostly formed in winter, when water is poor in biological life. Then, as the photic zone descends deeper, the water keeps its optical properties (high transparency), and phytoplankton in it almost does not develop because of the low temperature.

3. ε_{av}, m^{-1} – the average EC value at the depths multiple of 10 m in the layer from the sea surface to the depth of the minimum value. Such discreteness of EC values corresponds to the commonly accepted practice of representation of the field mission materials in the tabulated form. In this layer, the EC usually decreases with depth. At the same time, turbid layers connected with layers with density jumps (seasonal thermocline, halocline, etc.) are observed at different depths in summer period. No characteristic peculiarities are observed in the positions of these turbid layers. The characteristic ε_{av} allows qualitative assessment of the amount of suspended matter in the oxygen zone and characterizes water turbidity caused largely by the suspended matter of biological origin or, in other words, the level of biological productivity of the oxygen zone.

4. ε_{max}, m^{-1} – the maximum EC value in the deep turbid layer (DTL). It is situated near the top of the hydrogen-sulfide zone. In its value, ε_{max} is comparable with the EC value near the surface, and sometimes even exceeds it. Usually we observe one maximum in the DTL, but sometimes several maxima are observed. The upper maximum is usually the largest one and just it is taken as ε_{max}.

The mechanism of DTL formation and existence is still unclear. Hydrochemical analysis revealed a considerably increased content of organic carbon in this layer as compared with the upper and lower layers. Thorough studies of the suspended matter in this layer showed that it largely consists of dead phytoplankton, remains of organisms, and zooplankton faeces.

The absence of density jumps, which can accumulate particles deposited from the upper euphotic zone, in the DTL and location of this layer in the zone of coexistence of oxygen and hydrogen sulfide evidence of its connection with the geochemical processes. According to one hypothesis, the DTL is formed as a result of vital activity of some sort of carbothionic bacteria oxidizing sulfuric compounds with production of sulfates and molecular sulfur that lead to the EC increase.

Recent studies conducted in the Marine Hydrophysical Institute of the Ukrainian National Academy of Sciences show that molecular sulfur is not always present in the DTL. In some cases, considerable amounts of magnesium dioxide were found in it. Sometimes, both molecular sulfur and magnesium dioxide are absent, while the concentration of suspended organic matter is increased.

5. $Z\varepsilon_{min}$, m – the depth of ε_{min}.

6. $Z\varepsilon_{max}$, m – the depth of ε_{max}.

The spatial variability of these parameters is connected with the peculiarities of water circulation in the Black Sea. Because of cyclonic movement of water in the Black Sea at its periphery in the region of the Main Black Sea Current, barocline layers, in which ε_{min} and ε_{max} and their depths are determined, go down. Furthermore, deepening of barocline layers increases in the regions of anticyclonic vortices and meanders.

7. $\varepsilon_{200}/\varepsilon_{300}$ – the ratio of EC values in the hydrogen-sulfur zone at the horizons of 200 and 300 m. The horizon of 200 m corresponds to the top of the hydrogen-sulfur zone, and the main amount of EC measurements is obtained down to the horizon of 300 m (EC varies insignificantly deeper than 300 m). In the hydrogen-sulfide zone, the character of EC variation with depth depends on the radiation wavelength. In the longwave region of the visible spectrum (yellow, orange, and red regions), the EC keeps almost unchanged with depth, and in the shortwave region (blue, violet, and, especially, near ultraviolet regions) it increases. This spectral dependence is characteristic of light absorption by the so-called yellow substance – a part of dissolved organic compounds falling in the class of humic acids. Thus, the parameter $\varepsilon_{200}/\varepsilon_{300}$ in the shortwave spectral region can characterize qualitatively the amount of the yellow substance.

The selected characteristic EC values and their depth, in our opinion, optimally represent the main features of the vertical EC distribution in the upper 300-m layer of the deep part of the Black Sea. They are illustrated in the formalized EC profile (Fig. 1). The formalized profiles or individual EC values averaged over time and the observation space can be taken as reference ones, the comparison with which may give an estimate of the spatiotemporal variability of EC values and their depths, as well as additional information on the hydrophysical, hydrochemical, hydrobiological, and dynamic processes forming the EC structure.

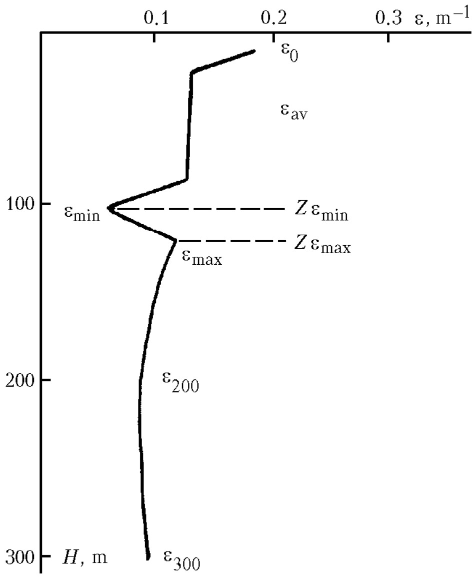

Fig. 1. Formalized vertical profile of the extinction coefficient.

In this paper, we present the results of many-year EC observations with a sensing transparency meter[6] designed in the Optical Division of the Marine Hydrophysical Institute. The obtained data are homogenous, representative, and comparable with each other. Materials of 10 expeditions of the Marine Hydrophysical Institute (about 500 stations) for the period of 1978–1986 were processed. The primary results of the EC measurements and the maps of the distributions of the selected optimal EC characteristics and their depths (λ_{eff} = 420–430 nm) that were drawn based on the primary data, as well as the calculated statistical estimates (mathematical expectation, standard deviation, and variation coefficient) for these expeditions were used in the Atlas of Extinction Coefficient in the Deep Part of the Black Sea.[7]

All the obtained data were divided into two periods: May–August and October–December, which were called mid-year (MY) and end of year (EY). The statistical estimates of the characteristics in these periods and the mean annual values (MA) are given in the Table, where ME is the mathematical expectation, SD is standard deviation, ν is the variation coefficient, and N is the number of stations. The annual statistical estimates of EC were used when plotting the formalized vertical EC profile (see Fig. 1).

To draw the maps of the spatial distribution of the optimal EC characteristics, the whole territory of the Black Sea was divided into 51 standard rectangles with the sides of 40′ latitude and 1° longitude by the technique accepted in hydrography.

The observations obtained in every rectangle were averaged for the studied period and assigned to the center of the rectangle. The maps of the annual spatial distribution of the EC optimal characteristics and their depth for the many-year period (1978–1986) are shown in Fig. 2.

Table. Statistical estimates of optimal EC characteristics for different parameters

Characteristic		ME	SD	ν	N	Measurement range
ε_0, m^{-1}	MY	0.22	0.1	0.46	277	0.04–0.64
	EY	0.15	0.05	0.35	200	0.04–0.65
	MA	0.19	0.09	0.48	477	0.04–0.65
ε_{av}, m^{-1}	MY	0.16	0.06	0.36	266	0.06–0.3
	EY	0.1	0.04	0.4	183	0.07–0.23
	MA	0.13	0.06	0.46	449	0.06–0.3
$\varepsilon_{\max}$, m^{-1}	MY	0.13	0.07	0.54	265	0.03–0.44
	EY	0.12	0.06	0.5	179	0.02–0.23
	MA	0.13	0.07	0.54	444	0.02–0.44
$\varepsilon_{\min}$, m^{-1}	MY	0.07	0.03	0.42	273	0.01–0.13
	EY	0.07	0.03	0.42	190	0.01–0.13
	MA	0.07	0.03	0.42	463	0.01–0.13
$Z\varepsilon_{\max}$, m	MY	124	25	0.2	263	80–210
	EY	124	22	0.18	186	70–180
	MA	124	24	0.19	449	70–210
$Z\varepsilon_{\min}$, m	MY	104	26	0.25	270	50–190
	EY	106	24	0.22	192	50–160
	MA	105	25	0.24	462	50–190
$\varepsilon_{200}/\varepsilon_{300}$	MY	0.86	0.12	0.14	261	0.5–1.0
	EY	0.87	0.08	0.09	188	0.5–1.0
	MA	0.86	0.1	0.11	449	0.5–1.0

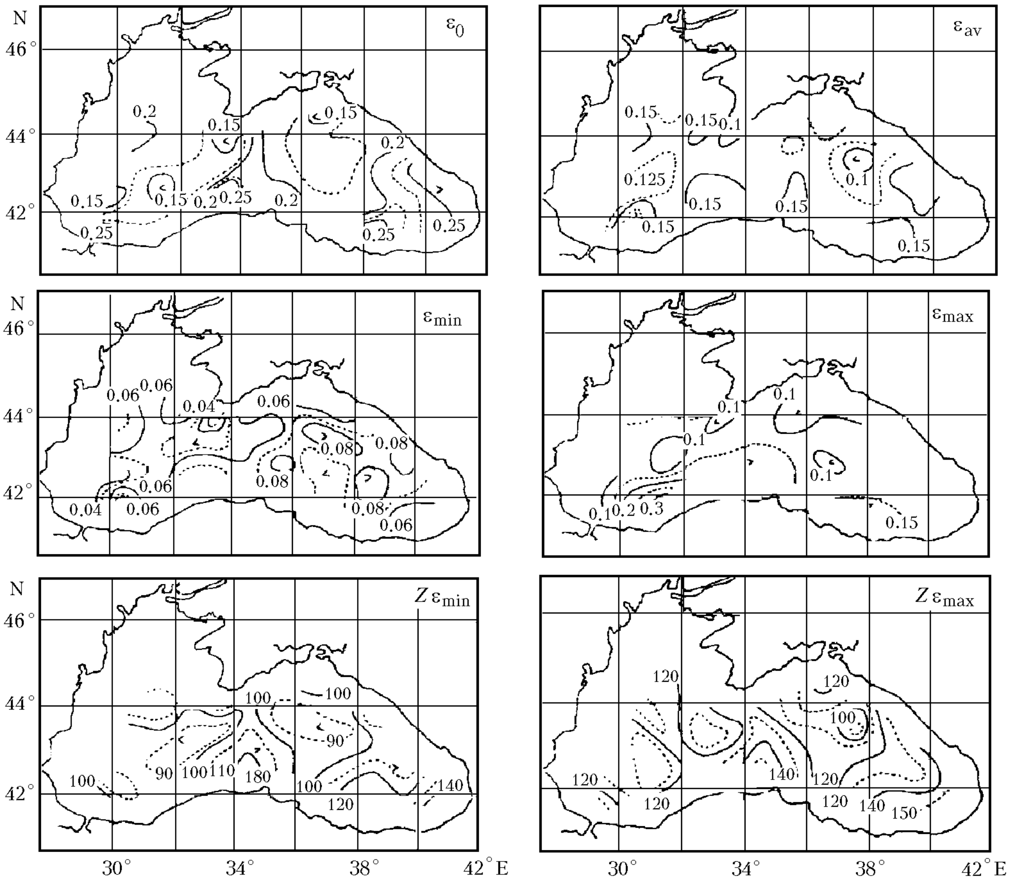

Fig. 2. Annual distributions of the optimal characteristics of the extinction coefficient in the deep part of the Black Sea.

Analysis of these results is of independent importance and can be done correctly involving various hydrophysical, hydrochemical, and hydrobiological data. However, even the tentative consideration of the observations reveals that the distributions of the considered EC characteristics depend on some dynamic and hydrochemical processes.

Thus, the zones with minimum values of these characteristics in the central regions of the eastern and western parts of the Black Sea coincide with the cyclonic circulation.[1] Sea regions with the enhanced values of the optimal characteristics (southeastern part, Bosporus region, southern regions) are connected with the zones of convergence and anticyclonic circulation. The comparison of simultaneous measurements of the depths of the EC maximum and the top of the hydrogen-sulfur zone obtained in 1984–1986 demonstrated their rather close values and distributions (mean correlation coefficient of 0.75–0.8).

In conclusion, it should be noted that the presented results (formalized vertical profile, statistical estimates, and distribution maps) can be used as reference data, since the array of the optical data was formed in the period of the stable hydrooptical situation in the Black Sea.

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