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The Structure of Fields of Oceanological Quantities in the Upwelling Zone at the Herakleian Peninsula (Crimea) in August 2019

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Abstract
Based on the data obtained during an expedition of Marine Hydrophysical Institute in August 2019, the paper considers the morphology of the fields of temperature, salinity, content of total suspended matter and coloured dissolved organic matter in two adjacent areas located along the north-west (area *1*) and south-west (area *2*) coasts of the Herakleian Peninsula. The authors used methods and approaches based on classical oceanographic analysis of the field structure of quantities under study. It is shown that in area *1* with the coastline oriented at an acute angle to the wind arrow, advective processes prevailed, and the structure of the fields of oceanological elements contained no anthropogenic features. In area *2*, the coastline of which is located along the normal to the wind arrow, the surge effect and the rise of water from deep horizons to the sea surface were noted. Here, in the water column, lenses with low salinity, increased content of total suspended and dissolved organic matter were found. These lenses arose under the influence of wastewater distributed in the upwelling ascensional circulation system from a nearby wastewater collector.

Keywords: temperature, salinity, total suspended matter, coloured dissolved organic matter, upwelling, contamination, Herakleian Peninsula, Crimea

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Структура полей океанологических величин в зоне апеллинга у Гераклейского полуострова (Крым) в августе 2019 года

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Аннотация
На основе данных экспедиции, проведенной Морским гидрофизическим институтом в августе 2019 г., рассмотрены закономерности структуры полей температуры, солености, концентрации общего взвешенного вещества и концентрации окрашенного растворенного органического вещества на двух смежных участках, расположенных вдоль северо-западного (участок *1*) и юго-западного (участок *2*) берегов Гераклейского полуострова. Использованы методы и подходы классической океанографии, основанные на анализе структуры полей рассматриваемых величин. Показано, что на участке *1* с береговой линией, ориентированной под острым углом к вектору ветра, превалировали адвективные процессы, а структура полей океанологических элементов не содержала антропогенных признаков. На участке *2*, береговая линия которого расположена по нормали к вектору ветра, отмечен сгонный эффект и подъем вод из глубинных горизонтов к поверхности моря. Здесь в толще вод обнаружены линзы с пониженной соленостью, повышенным содержанием общего взвешенного и растворенного органического веществ. Эти линзы возникли под влиянием сточных вод, распространявшихся в системе восходящей циркуляции апвеллинга из находящегося рядом коллектора.

Ключевые слова: температура, соленость, общее взвешенное вещество, окрашенное растворенное органическое вещество, апвеллинг, загрязнение, Гераклейский полуостров, Крым

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Introduction

The coastal water area of the Black Sea near the Herakleian Peninsula (Fig. 1) has been studied well enough. Currently, there are some publications [1–8] addressed to water dynamics, modeling, satellite studies of the distribution of pollutants [1), hydrochemical regime of the region [2). Particular interest in this water area is stipulated by the anthropogenic load on the marine environment that has been increased in recent years.

One of the recently published papers [9] analyses the current data on the sources of pollution in the coastal water area under consideration, the volumes of wastewater

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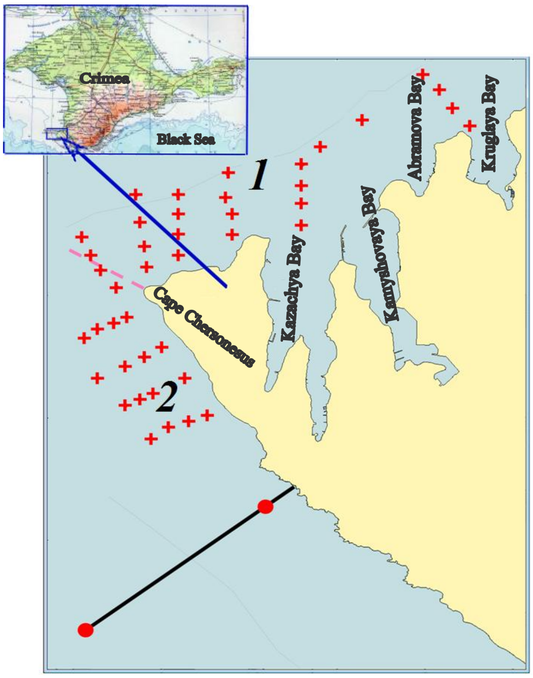
1) URL: http://dvs.net.ru/SWCrimea/stoki_ru.shtml

2) Korshenko, A.N., 2016. *Marine Water Pollution. Annual Report 2015*. Moscow: Nauka, 184 p. (in Russian).



F i g . 1 . Diagram of oceanographic stations of the survey conducted on August 23, 2019 (*1*, *2* – conditionally designated areas of the water area; black line with two red circles – the sewage treatment plant pipeline with two outlets). Inset map – the geographical position of the studied water area

entering it, and the chemical composition of pollutants. Only a few of the above stated publications include the analysis of the fields of oceanographic elements, which are used mainly as a background. From the point of view of oceanology, this coastal water area of the Crimean Peninsula remains insufficiently studied.

The aim of this article is as follows:

– on the basis of the expeditionary data, to identify patterns in the structure of the thermohaline field, as well as the concentration fields of total suspended matter (TSM) and coloured dissolved organic matter (DOM) near the coast of the Herakleian Peninsula;

– to determine the signs of anthropogenic effect on the marine environment in the structure of the fields of the analysed quantities;

– to consider the factors that form the coastal area of contamination.

Materials and methods

The analysis was based on the materials of the expedition organized by Marine Hydrophysical Institute on August 23, 2019, during which synchronous observations of temperature, salinity, TSM and DOM concentrations were carried out in the layer of 0–25 m. The survey was conducted according to the diagram of stations shown in Fig. 1. The depth range in the testing area made from 6 to 150 m. At each station, all four parameters of the environment were synchronously recorded in the *in situ* sounding mode with a depth step of 0.1 m using the *Kondor* Sounding Complex[3)].

[3)] URL: http://ecodevice.com.ru/ecodevice-catalogue/multiturbidimeter-kondor (Accessed: 8.03.2022).

It should be noted that TSM and especially DOM are classified as the most informative indicators of water quality. Currently, DOM is actively used internationally as an indicator of contamination (including bacterial one) of coastal sea and ocean areas [10–12].

At the moment, the maximum permissible concentration of TSM and coloured DOM as a numerical indicator of marine environment contamination has not been determined. Therefore, to assess the significance of the anthropogenic component in the concentration field of these substances, their actual content was compared with the concentration typical for the open waters of the Black Sea off the Crimean coast.

Based on the results of numerous expeditions, we found that in the upper water layer 20–30 m thick off the Crimean coast, the DOM content field was uniform. Its characteristic concentration varies within 1.4–2.1 mg/L, with the salinity making 18.2–18.4 PSU [13].

Parts of the water area subject to anthropogenic effect stand out against the surrounding background in the form of local maxima of the content of this substance. In the Sevastopol coastal area, the concentration of DOM of anthropogenic origin on the sea varies in the range of 2.2–14.8 mg/L. The maximum concentration of this substance was found in the area of the wastewater outlet of Balaklava, located east of the entrance to Balaklava Bay [14].

On the schemes of the horizontal distribution of this quantity, the isoline of the DOM concentration of 2.2 mg/L can be taken as a conventional border separating water with an anthropogenic component and water where the anthropogenic addition is insignificant. By the location of local maxima of DOM concentration, it is possible to determine objects that have an anthropogenic effect on the marine environment [13].

In accordance with [15], in the central part of the Black Sea, the TSM concentration makes 0.2 mg/L. In the Crimean coastal waters, which are not under anthropogenic load due to the influence of the coast and the bottom, it is much higher and makes 0.8 mg/L [16].

Therefore, the concentration of coloured DOM and TSM, 2 mg/L and 0.8 mg/L respectively, is conventional concerning the natural norm for the content of these substances in the Black Sea waters near the Crimean Peninsula.

When we speak about impurities, we use the definition *contamination* adopted from work [17]. Thus, *contamination* means the presence of a substance where it should not be or its concentrations above the background. *Pollution* results or can result in adverse biological consequences for local communities.

The formations found in the structure of the fields of the considered quantities, which did not characterize natural distribution and stood out against the surrounding background, were taken as signs of anthropogenic effect.

Results and discussion

The weather during the survey was determined by the southeastern periphery of the anticyclone with its center over Belarus. The survey was accompanied by the northern, northeastern wind with the average-per-day speed of 6 m/s. The wind speed reached 8–13 m/s at sea during the survey. The sea disturbance made 3-4 points.

For convenience of description and taking into account the peculiarities of the hydrological regime, we conditionally divide the entire water area under consideration into two areas. Area *1* includes waters of the north-west part of the Sevastopol coastal area, from Omega (Kruglaya) Bay to Cape Chersonesus. Area *2* includes waters washing the south-west coast of the Herakleian Peninsula. Area *1* is a relatively shallow (depth less than 30 m) water area, where the fields of the studied quantities were formed under the influence of advective processes. The state of the fields of oceanological quantities of area *2*, which is located above the slope, in an area with predominantly gentle relief and rather sharp increase in depth near the coast, was largely determined by the vertical circulation of water (Fig. 1).

In area *1*, with the coastline oriented at an acute angle to the wind arrow, the wind surge and the corresponding water transport towards the coast prevailed. In area *2*, the coastline of which is located along the normal to the wind arrow, the surge effect and the rise of water from deep horizons to the sea surface were noted. The structure of the water in the respective water areas was characterized by qualitative differences.

A natural boundary was observed between the selected areas in the form of a frontal section in the fields of all four analysed quantities, which was well expressed on the sea (Fig. 2) and indicated by a dotted red line in Fig. 1.

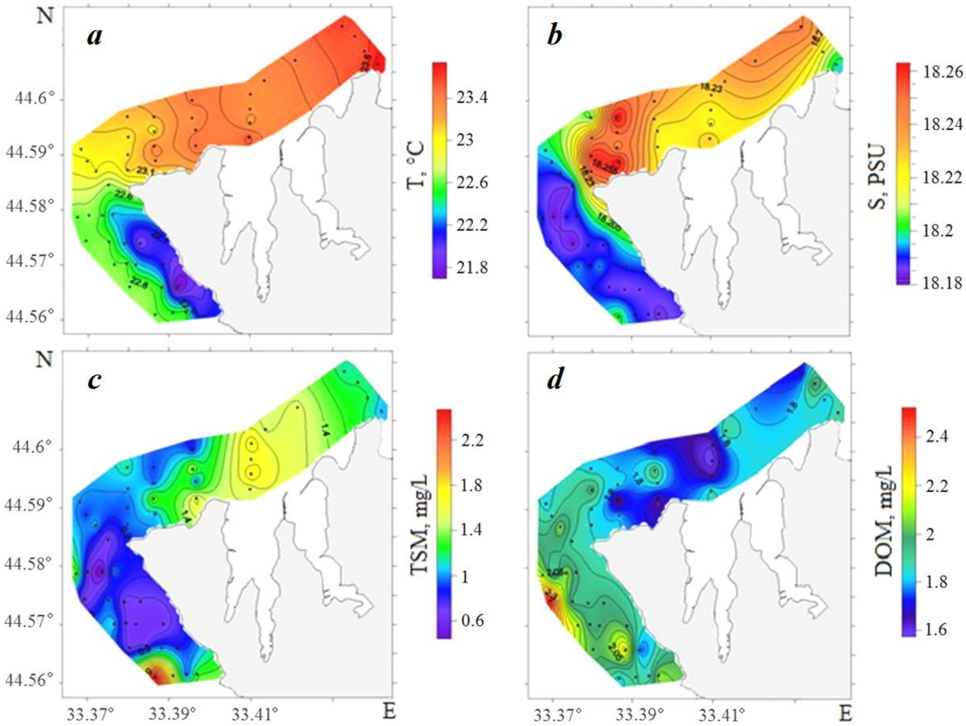
In area *1*, the water column was characterized by uniformity and parameters close to those of the water of the open part of the Sevastopol coastal area. There, water of elevated temperature and salinity with minimum content of TSM (0.6–0.8 mg/L) and DOM (1.6–1.8 mg/L) was transported from the north (Fig. 2).

In area *2*, on the sea, in the temperature field, an upwelling center (minimum 21.6–22.2 °C) is clearly visible, elongated along the south-west coast of the Herakleian Peninsula. In the fields of other elements on the sea surface, the surge effect is not so evident (Fig. 2).

The features of the vertical stratification of the analysed quantities in the subsurface water layer contain more detailed information about upwelling (Fig. 3).

In both areas, a two-layer vertical structure of the temperature field, typical for the summer season, was observed with a monotonically decreasing profile $T(z)$. The upper quasi-homogeneous layer 10–15 m thick was clearly marked. It was underlain by a seasonal thermocline, deeper than which the water temperature slowly decreased with the depth of up to 11–13 °C at 20–25 m horizons. In area *1*, the thermocline was located in the 13–20 m layer, and its surface was almost horizontal. In area *2*, influenced by upwelling, the thermocline was raised near the coast and was located at a shallower depth, among the horizons of 8–15 m (Fig. 3, *a*).

The salinity in the upper water layer in area *1*, equal to 18.1–18.3 PSU, was higher by 0.1–0.2 PSU compared to area *2*. That is, in the ascending circulation system, less saline water was exposed to the surface of area *2* (Fig. 3, *b*).

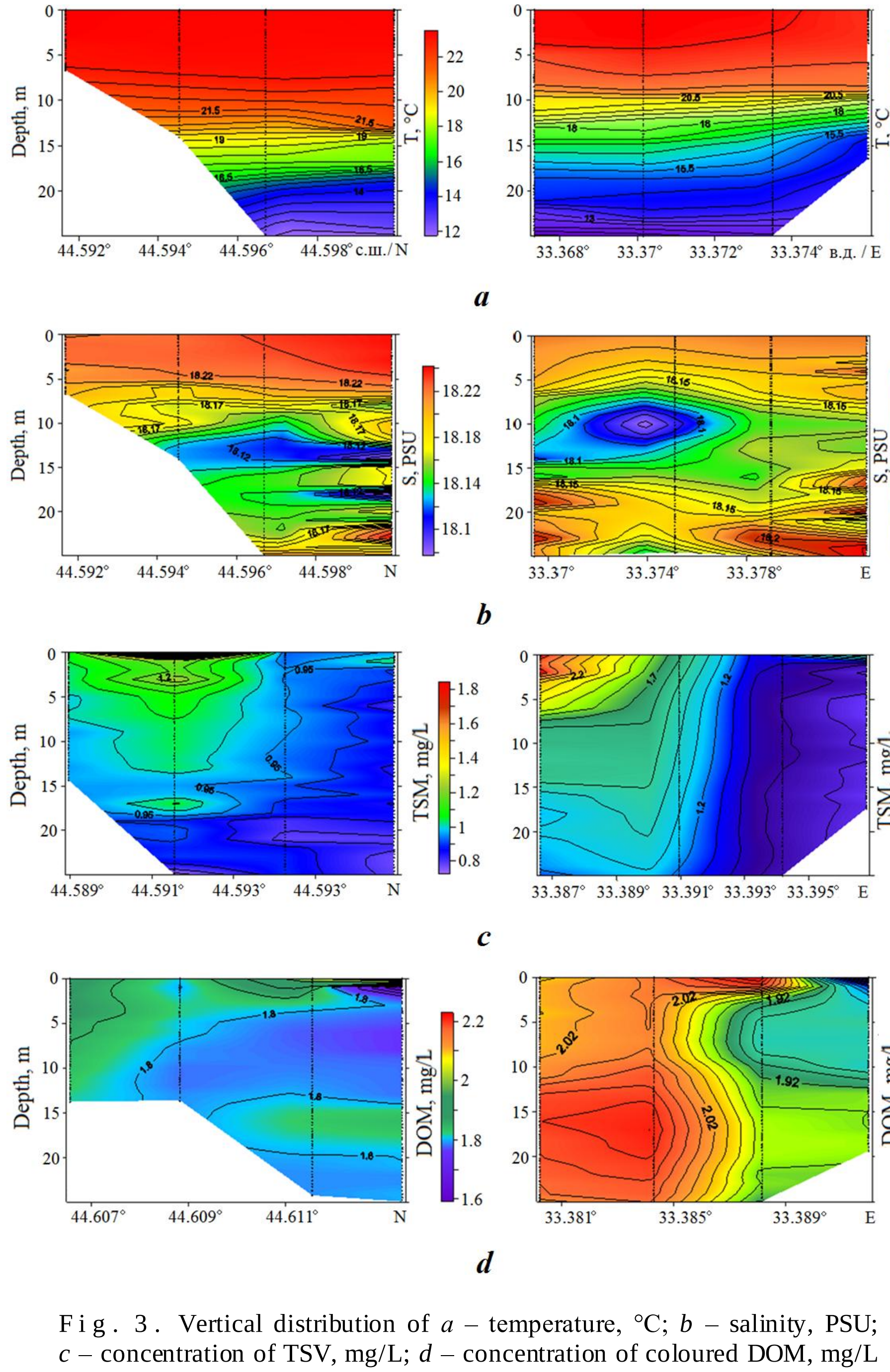


F i g . 2 . Distribution of *a* – temperature, °C; *b* – salinity, PSU; *c* – TSM concentration, mg/L; *d* – coloured DOM concentration, mg/L in the upper water layer in August 2019 according to the MHI expedition data

In contrast to the structure of the temperature field, the salinity field was relatively uniform along the vertical. From the surface to the lower sounding horizon, the salinity throughout the considered area varied within 0.2–0.3 PSU and was characterized by nonmonotonous vertical stratification. Distribution $S(z)$ is a nonmonotonous function of depth with an intermediate minimum located in the 5–20 m layer (Fig. 3, *b*).

An important element of the stratification of the haline field is the presence of structural heterogeneities in the subsurface water with their salinity reduced by 0.05–0.17 PSU relative to the surrounding background. These formations were most apparent in area *2*, where they were identified as separate lenses with a vertical and horizontal scale of about 10 m and 200–400 m (Fig. 3, *b*).

The structure of the TSM concentration field in the analysed areas also differed significantly. On the sea, in shallow area *1*, the TSM concentration varied in the range of 1.1–2.0 mg/L. The field of this quantity was characterized by homogeneity. On the surface of the predominant part of the water area in area *2*, the TSM content was minimal (0.4–1.1 mg/L), except for its extreme south area.



F i g . 3 . Vertical distribution of *a* – temperature, °C; *b* – salinity, PSU; *c* – concentration of TSV, mg/L; *d* – concentration of coloured DOM, mg/L in Section 1 (left) and in Section 2 (right) in August 2019 according to the MHI expedition data

Here, against the background of a low-gradient TSM field, a lens with its vertical scale of 5–7 m and maximum concentration of 2.4–2.5 mg/L within the entire considered water area was clearly distinguished, which was three times higher than the natural norm (Fig. 3, *c*).

In the vertical structure of the TSM concentration field, as well as in the structure of the haline field, inhomogeneities in the form of lenses with an increased content of this substance relative to the surrounding background, were revealed in the water column. Moreover, such structural formations were more often observed in area *2*, where they were more evident (Fig. 3, *c*).

The concentration field of coloured DOM also had noticeable structural differences. On the surface of the predominant part of the water area in area *2*, the content of this substance was close to the norm and made 2.0–2.1 mg/L. In the south-west part of this area, a lens with the maximum DOM concentration (up to 2.4 mg/L) was observed, which was traced throughout the entire water column from the surface to the lower sounding horizon. In most of the water area in area *1*, the concentration of DOM on the sea was minimal, 1.6–1.8 mg/L (see Fig. 2).

In the vertical structure of the concentration field of coloured DOM, as well as in the structure of the haline field and the TSM concentration field, individual lenses with an increased content of this substance were noted in the water column. Similar structural formations were more often observed in area *2*, where they were more apparent, and the concentration of DOM in their cores reached 2.5–2.7 mg/L exceeding the natural norm by 1.2–1.4 times (Fig. 3, *d*).

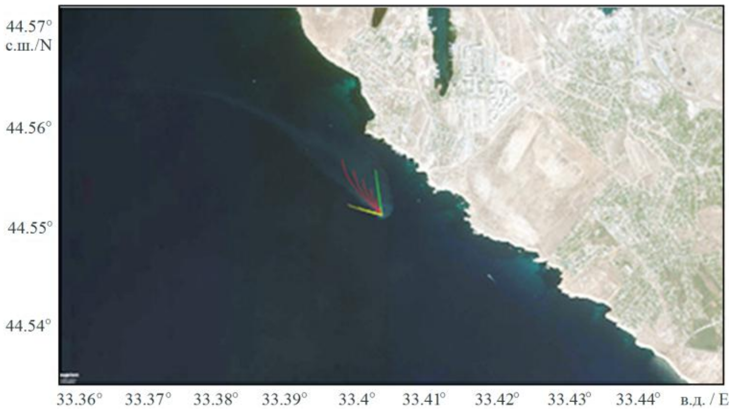
The above information indicates that the fields of salinity, TSM and DOM concentrations in area *2* had a component that was not present in area *1*. In area *2*, in the upwelling ascensional circulation system, water came to the sea surface from deep horizons, which had low salinity and high concentration of TSM and DOM exceeding the natural norm. That water was evidently of anthropogenic origin.

Based on the analysis of a series of hydrochemical surveys, numerical modeling methods and satellite hydrophysics [3–9], the main source of pollution of the considered water area has been established – wastewater collector of the *Yuzhnye* treatment facilities. The traces of the spread of wastewater from this source can be clearly visible on satellite images (Fig. 4).

Conclusion

Based on the data of the expedition conducted in the area of the Herakleian Peninsula in August 2019, the structure of the fields of temperature, salinity, TSM content and coloured dissolved organic matter (DOM) was analysed.

Two areas of the region under study are conventionally marked, namely: the water area located along the north-west (area *1*) coast and the water area near the south-west (area *2*) coast of the Herakleian Peninsula, where the fields of the analysed values were formed under the influence of various factors having their own properties.



F i g . 4 . Traces of the spread of wastewater from the collector of the *Yuzhnye* treatment facilities in the satellite image of the water area near the Heraclean Peninsula (*Google Earth* image)

In area *1* with the coastline oriented at an acute angle to the wind arrow, advective processes prevailed, and the structure of the fields of oceanological elements contained no anthropogenic features. In area *2*, the coastline of which is located along the normal to the wind arrow, the surge effect and the rise of water from deep horizons to the sea surface were noted. In the water column, lenses with low salinity, increased content of TSM and DOM were found, higher than the natural norm.

It is shown that the main source of pollution of the water area under consideration is associated with the wastewater collector of the *Yuzhnye* treatment facilities.

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Contribution of the authors:

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Alexey I. Chepyzhenko – measuring complex preparation; performance of expedition works; observation of currents, temperature, salinity, concentrations of TSM and DOM; raw data processing; main visual material preparation; paper text revision

All the authors have read and approved the final manuscript.