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Milestones in the History of the Black Sea Oceanography

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ABSTRACT

In this paper the main stages in the history of the Black Sea oceanography are briefly described from the middle ages to the present. It is shown that modern knowledge on the Black Sea and our understanding of hydrophysical and biochemical processes of this unique sea basin is reached as a result of hard research activity of a lot of researcher-oceanographers during last centuries. Significant attention is paid to the modern operative oceanography using modern data-computing technologies and satellite remote sensing methods.

Key words: Black Sea oceanography, numerically modeling

1. Introduction

The Black Sea, which is located at the border of Europe and Asia, played a connecting role between the West and the East since ancient times. The Black Sea was one of the most important link of the great silk road and played a crucial role in economic and trade relations of the old Georgia with Greek world and other countries [1, 2], that in the legendary form is reflected in the myth of the Argonauts. The Black Sea has many times become an object of attention not only to researcher-oceanographers, but also to the general public. Hundreds of articles and monographs are devoted to the Black Sea, since the XIX century many scientific expeditions have been carried out. Modern knowledge of the physical and biochemical processes in the Black Sea was formed over several hundred years as a result of tireless work and scientific activity of many researchers. The oceanography achieved the great successes especially in recent decades, which is the result of rapid scientific and technological progress.

In this paper the main facts and milestones in the development of the Black Sea oceanography from the middle ages to the present including the achievements of the modern Black Sea operative oceanography are shortly considered.

2. The Black Sea oceanography in XVII-XIX centuries

The modern configuration and morphometric parameters of the Black Sea formed approximately 7600 years ago, when the connection between the Black Sea and the World Ocean was restored through the Bosporus Strait [3, 4]. The main specific features of the Black Sea are due to the weak water exchange with the Mediterranean Sea, existence of hydrogen sulphide layer below depth of 150-200 m and a powerful river runoff. The ancient Greeks knew the Black Sea and Georgia very well, which is reflected in their myths and written monuments [5, 6]. Especially the great interest of the ancient Greeks belongs to the 7th century BC, when the Greeks began founding of Greek colonies on the eastern coast of the Black Sea.

Despite the fact that since ancient times the Black Sea has been a place of intensive navigation, knowledge of the processes taking place in the Black Sea practically did not advance until the XVII century. The first significant discovery in the history of the Black Sea oceanography belongs to the famous Italian diplomat, military man and oceanographer Luigi Ferdinando Marsili (1658-1730). In 1679, during his journey from Venice to Istanbul, the 21-year-old Marsili discovered the lower and upper currents in the

Bosporus [7-11]. In the history of the Black Sea oceanography it was the first most important investigation conducted by the direct measurements in the sea. On the basis of direct measurements of water densities and scientific analysis Marsili established the Bosporus exchange currents between the Black Sea and the sea of Marmara. His measurements in the Bosporus showed the surface water of Black Sea origin to be significantly lighter than the water samples from the undercurrent, which had weight consistent with the Mediterranean water [9]. Based on these initial observations, Marsili reached a good understanding of the pattern of circulation of the Strait of Bosporus and successfully constructed the first theoretical explanation of its hydrodynamics [9].

In order to confirm his discovery - the Bosporus water exchange, Marsili carried out a laboratory simulation of the Bosporus Currents. He demonstrated this density difference by building a physical model that captured the salient features of the phenomenon (Fig.1). Marsili made a two-compartment box with the divider connected by two openings at top and bottom, and showed that waters of different densities in the two compartments would flow to the opposite side in a manner consistent with his with his observations. Marsili understood that the Bosporus currents were a simple consequence of the different water densities in the Black and Mediterranean Seas.

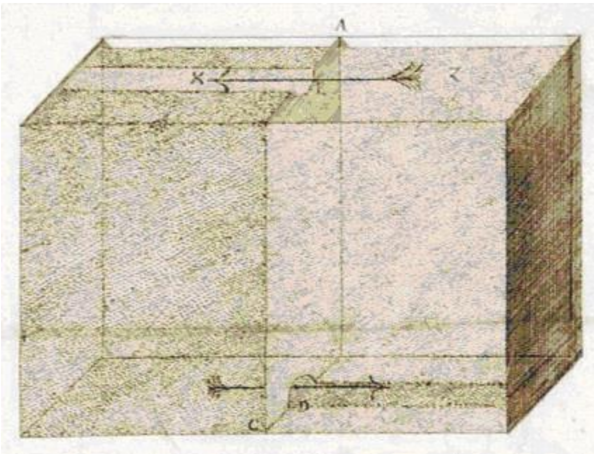

Fig.1. Luigi Ferdinando Marsili's physical model of Bosporus two-layer flow (Marsili's box) [7, 9].

The observations and experiments were published in the 1681 book by Luigi Ferdinando Marsili, originally published in Italian [7-10]. Thus the foundations of modern oceanography have been laid in Istanbul by Marsili, based on a series of first-time measurements in the Bosporus [11]. Subsequent studies have shown an important role of the Bosporus currents in the formation of the hydrological structure of the Black Sea.

In the XVIII century Russian sailors began a hydrographic description of the Azov and Black Seas [12]. These works continued in the XIX century. During the expedition (1825-1836) organized by a Russian military officer and hydrographer E. P. Manganary (1796-1868) mapping of the Black Sea and Azov coasts was carried out, resulting in the issuance of a map of the Black Sea atlas in 1842.

Systematic study of the Black Sea began in the second half of the XIX century, when it launched large-scale scientific expeditions. As D. M. Fillipov notes in his famous monograph [13], three stages in the Black Sea study are indicated in the manuscript of the famous Russian oceanographer N. I. Chigirin. The first stage - since the middle of the XIX century until 1890 was characterized by accidental hydrological observations conducted by Russian Black Sea Fleet Officers. As the beginning of the second stage should be considered the first Black Sea depth-measuring expedition led by Russian oceanographer and meteorologist I. B. Shpindler (1848-1919) in 1890-1891. The third stage begins since 1922, when the Azov-Black Sea research fishery expedition was organized under the leadership of N. M. Knipovich. At the same time a multi-year oceanographic expedition led by Russian scientist and oceanographer Yu. M. Shokalskiy (1856-1940) was organized. As the beginning of the modern stage can be considered 70-80s of the XX Century [14], The characteristic feature of this phase is the wide use of mathematical modeling methods and computing techniques in studying the Black Sea processes and developing modern remote (satellite) sensing and contact measurement methods.

At the first stage, as a result of the scientific works of F. F. Wrangell (1879), V. V. Maidel (1884), S. O. Makarov (1850), certain opinions were created on the surface circulation of the Black Sea, but at the same time a wrong opinion was formed about the great contribution of the rivers to the Black Sea circulation.

In 1885 famous oceanographer and the vice-admiral of the Russian fleet S. O. Makarov (1849-1904) has carried out detailed hydrological research of Bosporus two-layer current and thoroughly has established that less salty water of the Black Sea by the upper current enters into the sea of Marmara, and more salty water of the sea of Marmara by the deep current enters into the Black Sea. To conduct his research, Makarov used the Russian military vessel “Taman”, which was at the disposal of the Russian embassy in Istanbul. S. O. Makarov conducted detailed observations in the Bosporus Strait, including measurements of water temperature, salinity, velocity and direction of currents. Although the upper and lower currents of the Bosporus were known as a result of research conducted by Marsili, Makarov's merit should be considered a detailed hydrological study of the Bosporus flows and the substantiation for the hypothesis associated with the Bosporus two-layer current. He published the results of the researches conducted in the Bosporus Strait in the book "*On the exchange of waters of the Black and Mediterranean Seas*" awarded the prize of the Russian Academy of Sciences [12, 15].

Thus, researches carried out by L. F. Marsili and S. O. Makarov is an important event in the history of the Black Sea Hydrology, which strongly showed the existence of the Bosporus water exchange currents.

In 1870s started studies in the Black Sea biology. In this respect a major event was the establishment of the first marine biological station in Odessa (Soon the institute was transferred to Sevastopol) on the initiative of outstanding traveler, ethnographer and geographer Miklukho-Maclay (1846-1888). Its first director was Academician A. O. Kovalevsky. Nowadays it is a widely known institute of biology of the southern seas [12]. After the organization of the Sevastopol biological station, the study of the fauna and flora of the Black Sea became systematic. In the early XX century, based on the researches conducted in the biological station, the main knowledge of the Black Sea organic world were created. The absence of life was discovered in the deep Sea layers of the Black Sea Contaminated with hydrogen sulphide.

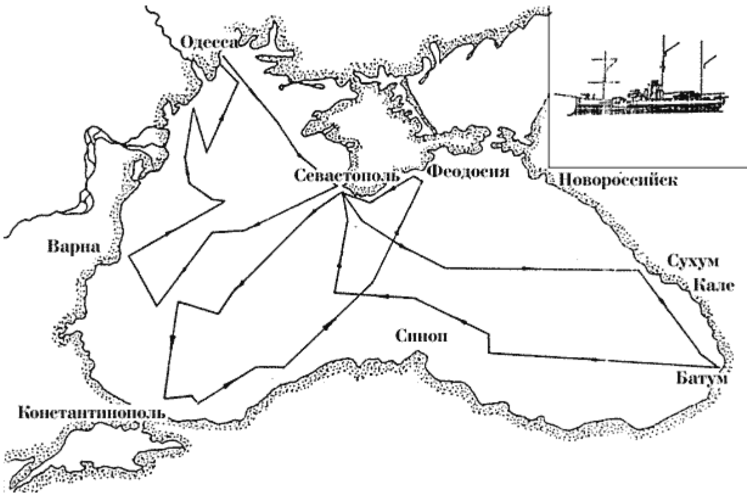

Fig.2. Spinldler’s expedition route in the Black Sea [16].

An important step forward in the study of the hydrology of the Black Sea was a complex depth-measuring oceanographic expedition during 1890-1891 led by I. B. Shpindler [4, 16, 17] by vessels “Chernomorec”, “ “Donec” and “Zaporotzec”. Hydrograph F. F. Wrangell, geologist N. I. Andrusov and chemist A. A. Lebedintsev participated in the expedition. In Fig. 2 the expedition route in the Black Sea is shown [16]. This expedition made a great contribution to the study of the Black Sea Hydropogy. During the expedition were made great discoveries, such as: 1) the cold intermediate layer at a temperature below 8^0C, 2) contamination of deep layers of the Black Sea by hydrogen sulfide and the absence of fauna, 3) waters with high salinity (34%o) at the Bosporus, which flowed into the Black Sea with deep flow from the Sea of Marmara. With this, it became clear that the deep layers of the Black Sea are a mixture of waters of the Marmara and Black Seas, 4) it has been proven that the bottom of the central part of the sea like a flat bowl is with the greatest depth of up to 2245 m, 5) monotonous growth of temperature and salinity from the depth of 200 m to the bottom up to 9^0C and 22,3%o, respectively.

One of the main results of the expedition was the discovery of a hydrogen sulfide zone below 200 m, but as is noted in [4], it was not the first discovery of hydrogen sulfide contamination in the Black Sea. In 1968 the exploratory expedition organized by the Hydrographic Department of the Maritime Ministry of the Russia, planned to investigate the routes of the international telegraph cable in the Feodosiya-Sukhumi section. During this expedition there was observed a difference between the surface and deep waters of the Black Sea, which was caused by the presence of hydrogen sulfide in deep layers. The great merit of the Shpindlers's expedition is that for the first time in the history of the Black Sea Oceanography the contamination of deep layers by hydrogen sulfide detailed and thoroughly investigated.

As a result of researches conducted during the expedition Shpindler came to the conclusion that the main cause of the sea surface circulation is wind. On the basis of the data received during the expedition he erroneously concluded that the Black Sea can be represented as a water body consisting of two parts - the surface and deep layers between which water exchange does not occur and deep layers of the sea are in a stagnant state. Such an opinion in the Black Sea Oceanography existed up to 30-40s of XX century [4]. Further studies have shown the incorrectness of such opinion. It turned out that the Black Sea is one whole system, where the water circulation occurs throughout the vertical from the sea surface to the bottom. In this respect there is very important the scientific article published by the famous marine biologist V. A. Vodianitskii, where on the basis of hydrobiological studies is formulated the scheme of vertical structure of the Black Sea general circulation [12, 18]. The principal provision of the author is that the whole thickness of the Black Sea represents one whole where the vertical and horizontal movements take place from the sea surface to the bottom, but the water exchange between the surface and deeper layers is slowly.

The expeditions led by Shpindler in 1890-1891 were the beginning of a systematic study of the Black Sea Hydrology, which essentially enriched the knowledge of the Black Sea and contributed to the study of general hydrology of the Black Sea. It should be noted that in 1892 the Russian Geographical Society awarded I. B. Shpindler and F. F. Wrangell with small gold medals for the successful expeditions and the great contribution to the Black Sea oceanography [4].

Up to the 20s of the XX century, large-scale complex oceanographic studies were no longer carried out, but in this period there were experimental studies of small scales. For example, in 1892 by A. A. Lebedintsev was carried hydrobiological and hydrological studies of the Black Sea from Odessa to Batumi section.

3. The Black Sea oceanography in XX century and at the beginning of XXI century

Since 1920s study of the structure and dynamics of the Black Sea have received very widespread development. In 1923-1935 a large oceanographic expedition was carried out, which was led by famous Russian scientist and oceanographer Yu. M. Shokalskiy (1856-1940). Since 1932 V. V. Shuleikin has become the leader of the expedition. The expedition work program was extensive and it consisted of standard hydrological examination to great depths, study of bottom and bottom sediments, hydrochemical studies, biologic studies of plankton and benthos, bacteriological investigations [12, 17, 19].

During the expedition, large-scale studies of the hydrochemical, biological and hydrological processes of the Black Sea were carried out. During the whole operation of the expedition 53 cruises were performed on various vessels, in which about 1600 oceanographic stations were made, more than 2000 biological and geological samples were collected. Most of the observations were made at the maximum depths of the sea (2000-2200 m). During the expedition, the first map of the Black Sea relief was drawn up, the general cyclonic nature of the Black Sea was established, the results obtained in previous studies about contamination of deep waters by hydrogen sulfides and the absence of living organisms were confirmed. Biological studies have shown the seasonal change of plankton and peculiarities of distribution of Benthos at the depth .

The ground samples taken under the expedition have become an important basis for geologists to study the history of the construction of the Black Sea Pavement and Development [12, 20].

The study of the vertical hydrological structure showed that the mixing process is carried out between the upper oxygen content and lower hydrogen sulfide layers, but with small intensity. Thus, the hypothesis of the existence of a standing zone in deep layers was refuted. It was found that in the open part of the Black Sea contaminated layer with hydrogen sulfide is up to 125 m depth, and close to the shores - up to 200 m.

It is interesting to note that Shokalskiy was a witness of a strong earthquake in Yalta on September 12, 1927, the epicenter of which was in the Black Sea close to the seashores. Despite the fact that he was not a seismologist, he gave a detailed description of this event and created a more complete picture of the Yalta earthquake [21].

The expeditions carried out in 1923-1935 were of great importancein the study of hydrophysical and biochemical processes. It should be noted that the works envisaged in the framework of the expeditions were entered into the second International Polar Year (1932-1933) Scientific Program.

Almost at the same time one of the most significant expedition in the history of the Black Sea oceanography was carried out in 1922-1928 – Azov-Black Sea research fishery expedition under the leadership of N. M. Knipovich. The main tasks planned in this expedition were biological, but the expedition plan included also hydrological observations [22]. The area of research and experimental activities of the expedition included the Azov Sea, the Kerch Strait and the coastal waters of the eastern part of the Black Sea.

By the expedition was obtained very extensive material covering the relief of the bottom, sea water temperature, salinity and the gas regime, the composition and distribution of plankton and benthos.The first monograph on the Black Sea hydrology belongs to N. M. Knipovich [23]. In his monograph the scheme of the surface circulation of the Black Sea is given, according to which the main elements of the surface circulation are the main cyclonic current, which surrounds the Black Sea on the periphery (the Rim Current), and two cyclonic eddies in the open part of the sea basin (so-called "Knipovich's glasses"). The cupola-shaped form of salinity and density fields at the centers of these eddies were established. The subsequent researches have confirmed the basic conclusions given by Knipovich.

It should be noted that as a result of performed oceanographic expeditions at the end of XIX century and in the 20-30s of the XX century the Black Sea became one of the most studied seas in the World.

It is necessary to note the great contribution of the Academician V. V. Shuleikin (1895-1979) to the many spheres of the Black Sea oceanography. In 1929 he has based the Black Sea hydrophysical station in Kaciveli (Crimea). Further, on the basis of this station the Marine Hydrophysical Institute was based (Sevastopol) and the station itself became an experimental division of this institution. Currently, the Marine Hydrophysical Institute is a research organization of international importance, where the studies of the Black Sea hydrophysical processes actively and at a high scientific level take place using modern experimental and theoretical methods. The works in Kaciveli hydrophysical station under the guidance of V. V. Shuleikin included a wide range of oceanographic tasks: dynamics of sea currents, dynamics of tidal waves, dynamics of surface and internal waves, physical basis of climate and weather, sea optics, sea acoustics, etc [17]. It is interested to note that in 1938 by Shuleikin was elaborated the method, which provided physical modeling of generation and evolution of wind driven waves in laboratory conditions in an aerodynamic circular channel. V. V. Shuleikin made a major contribution to the study of the heat balance of the Black Sea, which laid the basis for the modern theory of the Heat Balance of the oceans and seas. The scientific results obtained in the Hydrophysical Station during the nearly ten years are generalized in his fundamental monograph "Physics of the sea" [24]. The scientific results obtained by Academician V.V. Shuleikin received high recognition, which was confirmed by the fact that in 1942 he was awarded the title of laureate of the Stalin Prize for the major contribution to oceanography.

The leading role in the study of the Black Sea in the former Soviet Union played Scientific-research institutes in Sevastopol – Marine Hydrophysical Institute and the Institute of Biology of South Seas, that were equipped with scientific-research vessels "Mikhail Lomonosov", "Academician Vernadskiy", "Professor Vodianitskiy", etc. Significant scientific and research works also were carried out by the State Oceanographic Institute (Moskow) and M. Lomonosov Moscow State University, research vessels of which were based in Sevastopol. In the sea city of Gelendzhik the south branch of Shirshov Inctitute of Oceanology of the Academy of Sciences of USSR was functioning, which carried out the scientific expeditions by the research vessels "Academician Shirshov" and "Academician S.Vavilov".

The knowledge acquired for the 60s of the XX century about the Black Sea is reflected in the book "*Regional Oceanography* " by A. K. Leonov [25] and in the monograph "*Circulationand structure of waters of the Black Sea*" by D. M. Fillipov [13].

Since 50-60s of the last century, the study of the Black Sea has become deeper and more completed. In 1957-1959, in the framework of the International Geophysical Year Program, oceanographic expeditions were carried out in the former Soviet Union where the observations were conducted on the polygons. This made it possible to study the mesoscale variability of the Black Sea thermochaline structure and flows [12].

In the former USSR in 1976-1978, a joint program of Black Sea Complex Studies (SKOICH) was implemented. A wide range of rich scientific materials collected, analyzed and theoretical generalized in the scope of this program were published in a number of publications. First of all it should be noted the monograph by A. S. Blatov, N. P. Bulgakov, et al [26], where a broad spectrum of hydrophysical processes of the Black Sea is discussed. Here are the peculiarities of the average multi-year season changeability of the main hydrophysical fields - temperature, salinity, density and flow.

It is very important the contribution of the Bulgarian scientists to the study of Black Sea Oceanography, which carries out at the Institute of Fish Resources and the Institute of Oceanology of the Academy of Sciences of Bulgaria in Varna. Studies are mainly focused on the oceanography of the western part of the sea and the Bosporus region. The resulting findings are reflected in the collective work of Bulgarian scientists [27].

Research in Black Sea Oceanography in Romania carries out at Grigol Antipa Institute of Sea Studies in Constanta. The main attention is paid to the shelf zone and the Danube river delta.

Turkey's scientific and educational centers - the Center for Sea Science and Technology (Izmir), the Middle East Technical University (Ankara) and others have a major role in the study of hydrology and ecosystem of the Black Sea Anatolian coast.

The interest of American scientists with the Black Sea is very high. By the end of the 60s and in 70s-80s of the last century, they conducted a number of oceanographic experiments on the Black Sea, mainly related to the geological problems of the Black Sea [12]. A lot of publications of American scientists are devoted to mathematical modeling of the Black Sea dynamics (for example, [28-30]).

Obviously, it is not possible to receive the quantitative characteristics of the dynamics of the entire Black Sea basin only by observations. In this case it is necessary to apply the theoretical analysis methods.

Since 40-50s of the last century wide use of physical and mathematical methods in study of the Black Sea dynamics began, but fast development of computer facilities considerably has promoted numerical modeling of hydrophysical processes since 60-70s.

The modern stage of the study of the Black Sea, beginning since 70s of the last century, is distinguished with applying both the experimental and theoretical methods. The numerical modeling of the physical processes of the Black Sea, based on the full equation system of ocean hydrothermodynamics, was initially started in the former USSR during this period, particularly, at the Computing Center of the Siberian Branch of the Academy of Sciences of USSR (Novosibirsk, Akademgorodok) under the guidance of Academician G. I. Marchuk.

The method of mathematical modeling implies the description of the study object or process through differential equations that can be solved using appropriate boundary and initial conditions. This method enables to simulate processes and events ongoing in the nature (numerical experiments on a personal computer), evaluate various factors impact on the development of the study process and, finally, to predict it.

There are a lot of number of publications dedicated to mathematical modeling of physical processes in the Black Sea. The review and analysis of these publications are given in monographs [31, 32], which reflect the state of the problem for the 80s of the last century. There were developed two types of numerical models: diagnostic and prognostic. Among them diagnostic models are relatively simple in which the density field is determined based on the observation data. This allows simplification of the equation system, as it is not necessary to consider the equations of heat and salinity transfer. As input data for the diagnostic models the average multi-year seasonal sea density fields and atmospheric pressure above the sea were used. The first calculations were carried out using a diagnostic model on the basis of a stationary barotropic model for the north-western part of the Black Sea [33]. The calculations for the whole Black Sea Basin using the diagnostic models are also presented in [34-37]. A review and analysis of such models are in the monograph [38]. Calculations carried out by the diagnostic method have shown that movement of water in the Black Sea takes place throughout the thickness of the sea from the surface to the bottom. Vertical velocity received on the basis of the continuity equation demonstrated the rise of water masses above the central areas of the sea and lowering in the peripheral part of the sea at a rate of 10^{-4} cm /s [34].

diagnostic models are limited to explain the main features of the sea dynamics. In this respect prognostic models are very promising, in which the density field is given not on the basis of observational data, but is determined in the process of integrating the model equations. Prognostic models are divided into one-component and two-component models. One-component models were proposed in [39-42]. In [39], instead of the equations of heat and salinity, the equation for the density was used, and in [40-42] the density was determined only by the temperature field. For the Black Sea, such an assumption is rather crude, since, as is well known, the formation of a density field in the Black Sea basically depends on the salinity field.

Two-component prognostic models are more complete. They are based on a full system of ocean hydrothermodynamics equations. In this case the density field is determined by temperature and salinity fields. The first works in this direction were made at the Computing Center of the Siberian Branch of the Academy of Sciences of USSR (Novosibirsk, Academgorodok) in [32, 43-46]. In these works, the model equation system is formulated for deviations of thermodynamic values from the standard vertical distribution. For solution of the equation system the two-cycle splitting method with respect to physical processes, coordinate lines and planes is used proposed by Academician G. I. Marchuk to solve the dynamics and ecological tasks of the ocean and atmosphere [47, 48]. This was the first prognostic model of the Black Sea dynamics based on a full system of ocean hydrothermodynamics equations, the results of which confirmed the general cyclonic nature of the Black Sea circulation and showed a significant role of the bottom relief in circulation, particularly in the north-west part of the Black Sea. The maximum concentration of salinity was obtained in the central part of the sea, while the peripherals were relatively small, giving evidence of saline deeper water in the central areas of cyclonic rotation. It was also shown that the density and salinity fields in the Black Sea are in good correlation with each other.

The level of computing techniques of the 70s of the last century did not provide realization of non-stationary spatial tasks with the desired resolution. Therefore, the Black Sea dynamics prognostic baroclinic model was realized for the Black Sea basin with a horizontal grid step of 37 km, while 13 calculated levels were taken on a vertical [32, 43-46].

The two-component prognostic models of the Black Sea dynamics were also proposed in [49-51]. As a result of realization of the model [49] using Bryan's numerical scheme [52] the average annual and seasonal fields of hydrophysical characteristics were calculated. Comparison of model fields with observation data showed that the model satisfactorily reflected the peculiarities of hydrophysical fields. It should be noted that the Rim current was well reflected in the average annual picture of the calculated flow, but at the same time the internal cyclone eddies in the open part of the basin practically did not observed.

In [50-51] the model system of equations was solved using the two-cycle splitting method, as well as in [32, 43-46]. Numerous numerical experiments showed that the model well reflected the general features of the general circulation of the Black Sea.

In 70-80s of the last century large horizontal spacing applied in the numerical models did not allow description of small coastal eddies. The modern observations show existence of mesoscale and submesoscale eddies in coastal waters [53, 54], whose identification require very high resolution of mathematical models. The fast development of computational facilities since 1990s gave the opportunities for computer realization of these models with higher resolution, which have allowed reproducing dynamic processes in the Black Sea by the great adequacy.

Since 1990s at M. Nodia Institute of Geophysics of the National Academy of Sciences of Georgia the perfection of the Black Sea dynamics model [32, 43-46] was carried out by considering the main physical factors and simultaneously increasing the horizontal resolution of the model as in the horizontal (5 km horizontal), as well as in vertical direction (32 calculated level). The modern version of the model [55-57] provides the following key factors:

- quasi-real sea bottom relief and configuration of the sea basin,
- atmospheric wind and thermohaline impacts,
- solar radiation absorption by the upper layer of the sea,
- water exchange through the Bosporus Strait with Mediterranean Sea,
- Danube river runoff,
- space-temporal Changeability of turbulent viscosity and diffusion coefficients.

Performed numerical experiments in conditions of alternation of climatic wind fields typical for the Black Sea basin showed that surface circulation is constantly changing throughout the year. Strong atmospheric winds over the Black Sea have a smoothing effect on the surface sea circulation and the processes of vortex formations are less intense. In such cases, the speed of the sea current may exceed 100 cm/s. Later this basin-scale model was adapted to the easternmost water area of the Black Sea (including Georgian coastal zone) with increasing space resolution to 1 km.

The numerical modeling of the Black Sea dynamics is particularly intensively developing in the last 20 years and the number of publications devoted to this problem increases (for example, [58-65]). The results of mathematical modeling, hydrological observations and satellite remote sensing data clarified the traditional picture of the Black Sea circulation, obtained by N. M. Knipovich [23], and improved our knowledge of the dynamic processes taking place in the Black Sea. The Black Sea circulation is one of the major factors determining distribution of thermohaline fields and some substances of anthropogenic and natural origins. On the basis of modern research it became possible to establish the main regularities of the Black Sea circulation, which can be characterized as follows: the circulation of the Black Sea as a whole is cyclonic, the main element of which is the main Black Sea current (the Rim Current) by a cyclonic ring, which covers the Black Sea basin on the periphery over the continental slope and represents a jet flow with width about 40-80 m. Along the Rim Current jet around the basin flow speeds are about 25-30 cm/s, but the maximum speed of the flow at a strong atmospheric wind can exceed 100 cm/s. The Rim Current is observed throughout the year and is strengthened and stabilized during the autumn-winter period. The essential feature of the Black Sea surface circulation is also formation of some interior cyclone eddies in the western and eastern open parts of the Black Sea. the Rim current is hydrodynamically unstable and as a result of interaction with the relief it experiences meandering, especially during the warm period from April to November. This event is due to the weakening of the atmospheric winds and a number of calm situations during the warm period of the year. The meandering promotes generation of coastal anticyclonic eddies between the Rim Current and the coast over the entire perimeter of the seaside line. Such coastal eddies are: Bosporus, Sevastopol, Crimea, Caucasus, Sakaria, Sinop, Batumi eddies, etc. Among these eddies Batumi anticyclonic eddy is more intensive and stable formation, especially in the warm season. The coastal anticyclonic eddies and interior cyclonic eddies schematically are presented in Fig. 3 [66]. Characteristic sizes of coastal eddies are in a wide range about within 20 - 200 km, which play an important role in ventilation of coastal waters [67].

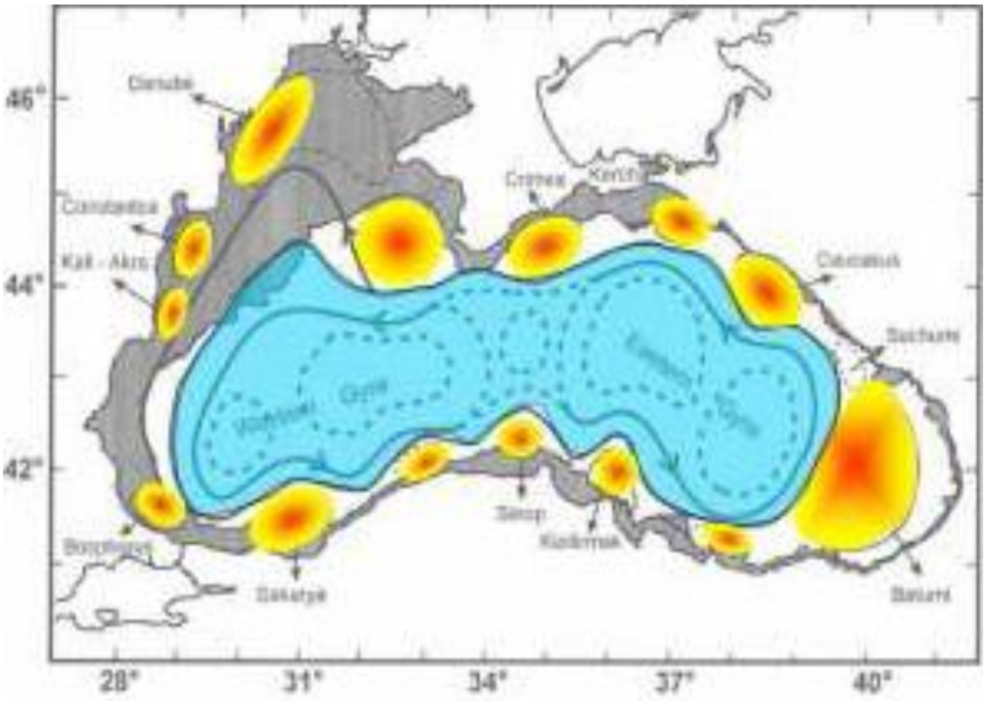

Fig. 3. A schematic structure of the Black Sea upper layer circulation [66] by showing of the Rim Current and cyclonic and anticyclonic eddies. By blue color cyclonic eddies are shown and by yellowish-reddish color - coastal anticyclonic eddies.

Approximately during last two decades the Black Sea oceanography achieved significant successes. Development of in-situ and remote sensing methods and effective data-computing technologies promoted creation of the Black Sea Nowcasting/Forecasting system, which is the large scientific and technical achievement of the Black Sea operative oceanography [68-72]. Such system allows to carrying out continuous control over the current state of the Black Sea and its change for some days forward. At present the Black Sea nowcasting/forecasting system is functioning in the near-real time and provides the short-range forecast of basic hydrophysical fields – the current, temperature, salinity and sea level. The main components of this system are basin-scale model of the Black Sea dynamics of MHI and some high-resolution models of coastal dynamics. In Fig. 4 the regional water areas of Bulgaria, Romania, Ukraine, Russia and Georgia are presented, where calculation of regional forecasts are carried out [70]. One of them is an easternmost water area including Georgian coastal zone. For this area operates the regional forecasting system developed at M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University [73-78] within EU international scientific projects ARENA and ECOOP. The regional forecasting system, which is one of the main components of the Black Sea nowcasting/forecasting system, consists of hydrodynamic and ecological blocks. The hydrodynamic block includes M. Nodia Institute of Geophysics high-resolution 3D regional model of the Black Sea dynamics with 1 km resolution which is nested in the basin-scale model of the Black Sea dynamics with 5 km resolution of Marine Hydrophysical Institute (MHI, Sevastopol) [62]. The ecological block includes 2D and 3D transport models of polluting substances.

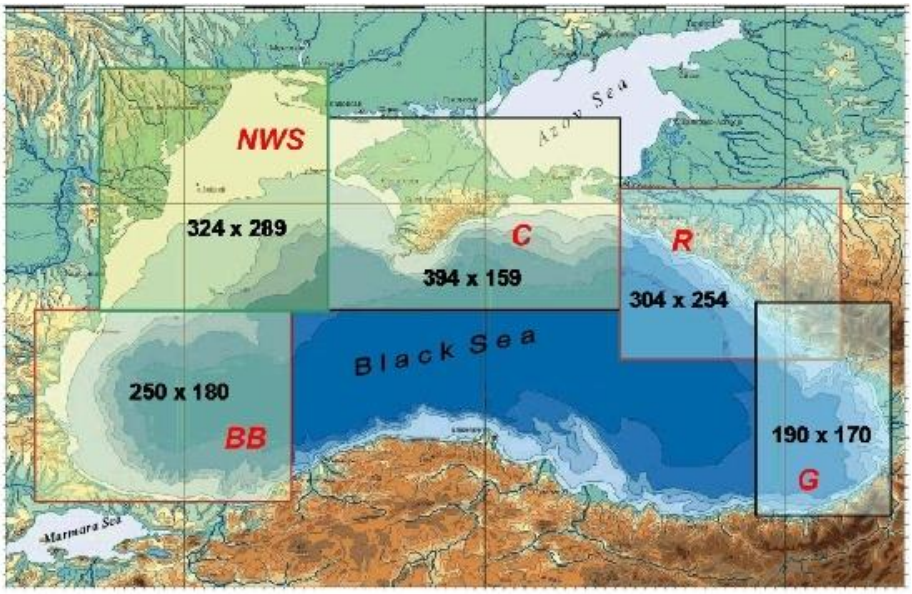

Fig.4. Black Sea coastal regions where are calculated regional forecasts with high-Resolution [70].

The regional forecasting system provides 3 days' forecast of main hydrophysical fields - the current, temperature and salinity with 1 km spacing in the Georgian sector of the Black Sea and surrounding water area, but in accidental situations – also the forecast of spreading oil and other polluting substances.

4. Conclusions

The Black Sea, which is typical inland water body, since ancient time was in focus by geographers and travelers, but its systematic and intense scientific study began in the second half of the XIX century. Though the first significant discovery occurred in the XVII century, when the famous Italian diplomat, military man and oceanographer Luigi Ferdinando Marsili in 1679 discovered the lower and upper currents in the Bosporus Strait.

The largest contribution to the Black Sea oceanography was made by expeditions led by I. B. Shpindler (1890-1891), Yu. M. Shokalskiy (1928-1935), N. M. Knipovich (1922-1928). the results obtained in these expeditions made the Black Sea the most studied sea in the World.

The development of remote sensing from artificial earth satellites, the elaboration of high-resolution mathematical models and assimilation methods of observational data in the last two decades have provided the creation of the Black Sea nowcasting/forecasting system, which is a large achievement of the modern Black Sea oceanography.

References

[1] Beradze Sh. A role of the Black Sea in the foreign-trade relations of Georgia (historical overview). Proceed. of the 2nd International Silk Road Symposium "BSEC Studies", 6, 7 May, 2005, Tbilisi, Georgia, pp.71 -75.
[2] Alasania G. The Black Sea. Proceed. of the 2nd International Silk Road Symposium "BSEC Studies", 6, 7 May, 2005, Tbilisi, Georgia, pp.39-43.
[3] Dimitrov P., Dimitrov D. Black Sea, flood and ancient myths. Varna, Slavena, 2008, 90 p, (in Russian).
[4] Grishin M. G., Sizov A. A. Black Sea depth-measuring expedition (1890-1891). Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2011, Iss. 25, vol. 2, pp. 444-450, (in Russian).
[5] Strabon. Geografiya. Moskva, Nauchno-izdatelskii Centr "Ladimir", 1994. 943 p (in Russian. http://naturalhistoryl.narod.ru/Person/Lib/Strabon/Index.htm.
[6] Flavius Arrianus. Mogzauroba shavi zgvis garshemo (Periplus Pontou Euxeinus), Tbilisi, 1961 (in Georgian).

[7] Soffientino B., Pilson M. E. Q. The Bosporus Strait. A special place in the history of oceanography, vol. 18, № 2, pp.17-23.
[8] Pinardi N., Moroni F., Ozsoy E., Marsili's first scientific ceanographic cruise (1679-1680) and exposition of Bosphorus density currents. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id=20&Itemid=35 .
[9] Ozsoy E., Pinardi N., Moroni F. Marseli's current measurements in the Bosphorus. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id =19&Itemid=34.
[10] Ozsoy E., Pinardi N., Moroni F. A. Scientific biography of Luigi Ferdinando Marsili. http://linux-server.ims.metu.edu.tr/index.php?option=com_content&view=article&id =16&Itemid=31.
[11] Ozsoy E., Sozer A., Gurses O., Tutsak E., Gunduz M., Sannino G. The leading role of the Turkish Straits system in ocean science and the environmental degradation imposed on unique Natural-Cultural Heritage by Canal Istanbul. https://www.academia.edu/19447211/The_Leading_Role_of_the_Turkish_StraitsSystem_in_Ocean_Science_and_the_Environmental_Degradation_Imposed_on_Unique_Natural-Cultural_Heritage_by- Canal_%C4%B0stanbul.
[12] Ivanov V. A., Kosarev A. N., Tutzilkin V. S. To history of expeditionary oceanographic studies in the Black Sea. Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2004, Iss.10, pp. 9-16 (in Russian).
[13] Fillipov D. M. Circulation and structure of waters of the Black Sea. Moskva, Nauka, 1968, 132 p (in Russian).
[14] Hydrometeorology and Gydrochemistry of the USSR seas. t. IV, the Black Sea. Iss.1 (Eds. A. I. Simonov, E. M. Altman), Sankt-Peterburg, Gidrometeoizdat, 1991, 428 p (in Russian).
[15] Makarov S. O. On the exchange of waters of the Black and Mediterranean Seas. Oceanograficheskie raboty, Moskva, Gidrometeoizdat, 1990, pp.31-93 (in Russian).
[16] Ignatiev C. M. Amazing sea body. Priroda, 2001, № 5, pp. 92-96 (in Russian).
[17] Grishin M. G. Research of physical properties of the Black Sea in 1920-1930. Short review. Ecological Safety of Coastal and Shelf Zones and Comprehensive use of Shelf Resources. Collected scientific papers, Sevastopol, 2011, Iss.25, vol.2, pp.435-443 (in Russian).
[18] Vodyanitskiy B. A. The main water exchange and the history of formation of the salinity of the Black Sea. Procced. of Sevastopol biological station. 1948, t. 6, pp.386-432 (in Russian).
[19] Zubov N. N. Domestic seafarers - researchers of the seas and oceans. Moskva, 1965, 474 c., (in Russian).
[20] Arkhangelskiy A. D., Strakhov N. M. Geological structure and development of the history of the Black Sea. Leningrad, AN CCCR Press, 1938, 149 p (in Russian).
[21] Shokalskiy Yu. M. Earthquake of September 12, 1927, Priroda, Moskva, 2006, № 9, pp.67-70 (in Russian).
[22] Pakhotnic A. F. A brief history of expeditionary researches in physical oceanology in the USSR. Moskva, Hayka, 1970, pp. 75-155 (in Russian).
[23] Knipovich N. M. Hydrological studies in the Black Sea. Proceed. of Azov-Black Sea research fishery expedition, 1932, issue 10, 272 p (in Russian).
[24] Shuleikin V. V. Physics of the Sea. Moskva, Nauka, 1968, 1083 p.
[25] Leonov A. K. Regional oceanography. Part 1. Leningrad, Gidrometeoizdat, 1960, 765 p (in Russian).
[26] Blatov A. S., Bulgakov N. P., Ivanov A. N., Kosarev V. S., Tutzilkin V. S. Variability of hydrophysical fields of the Black Sea. Leningrad, 1984, 240 p (in Russian).
[27] Black Sea. Leningrad, Gidrometeoizdat, 1983, 240 p (in Russian)
[28] Kara A. B., Hurlburt H. E., Wallcraft A. J. Black Sea mixed layer sensitivity to various wind and thermal forcing products on climatological time scales. Journal of climate, 2005, .18, № 24, pp.5266-5293.
[29] Kara A. B., Wallcraft A. J., Hurlburt H. E. Sea surface temperature sensitivity to water turbidity from simulations of the turbid Black Sea using HYCOM. J. Physic. Oceanography, 2005, v.35, №1, pp.33-54.
[30] Kara A. B., Wallcraft A. J., Hurlburt H. E. How does attenuation depth affect the ocean mixed layer? Water turbidity and atmospheric forcing impacts on the simulation of seasonal mixed layer variability in the turbid Black Sea. J. Climate. 2005, v.18, № 2, pp.389-409.
[31] Stanev E., Truhchev D., Roussenov V. The Black Sea circulation and its numerical modeling. Universitetsko izdatelstvo "Kliment Oxridski", Cofiya, 1988, 220 p (in Russian).
[32] Kordzadze A. A. Mathematical modeling of dynamics of sea currents (Theory, algorithms, numerical experiments), Moskva, 1989, 218 p (in Russian).
[33] Tolmazin D. M., Shnaidman V. A. et al. Problems of dynamics of waters of the north-western part of the Black Sea. Kiev, Naykova dumka, 1969, 130 p (in Russian).

[34] Barishevskaya G. I. Vertical movements of water masses in the Black Sea. Proceed. of BGMO CHAM, 1967, issue 5, pp.3-18 (in Russian).
[35] Gamsakhurdiya G. R. Investigation of three-dimensional circulation of the Black Sea waters by numerical models in the framework of diagnostic model. Moskva, Institute of oceanology of Academy of Science of USSR, 1975, Dep.in VINITI, № 1832-75, 27 p.
[36] Gamsakhurdiya G. R., Sarkisian A. C. Diagnostic calculations of current velocities on 11 horizons for the Black Sea. Okeanologia, 1975, t. 15, № 2, pp. 239-244 (in Russian).
[37] Djioev T. Z., Sarcisian A. C. Prognostic calculations of the currents in the Black Sea. Izv. AN CCCR, Fizika atmosfery i okeana, 1976, t.12, № 2, pp. 217-223 (in Russian).
[38] Sarcisian A. S. Fundamentals of the theory of calculating ocean currents. Leningrad, 1966, 123 p (in Russian).
[39] Djioev T. Z. Investigation of circulation of the Black Sea waters by numerical methods. Dissertation for the degree of candidate of physical and mathematical sciences. Moskva, 142 p (in Russian).
[40] Girgvliani A. G. Numerical study of dependence of hydrological characteristics of the Black Sea on seasonal variability of atmospheric processes. Preprint № 537, Novosibirsk, VC CO AN CCCR, 1984, 13 p (in Russian).
[41] Zalesny V. B., Kordzadze A. A., Girgvliani A. G. Numerical modeling of seasonal variability of hydrothermodynamics of the Black Sea. In: Numerical solution of ocean dynamics problems. Novosibirsk, 1982, pp. 25-36 (in Russian).
[42] Kordzadze A. A.,Girgvliani A. G. Perspectives of use of hydrodynamics models in problems of the Black Sea ecology. In: Materials of Conference “Ecology and regional use of the natural resources of the south region of Ukraine”, Sevastopol, part 3, pp. 449-454 (in Russian).
[43] Marchuk G. I., Kordzadze A. A., Skiba Yu. N. Calculation of main hydrophysical fields of the Black Sea on the bases of a splitting method. Izv. AN CCCR, Fizika atmosfery i okeana, 1975, t.11, № 4, pp. 379-393 (in Russian).
[44] Kordzadze A. A., Skiba Yu. N. About one numerical method of solving two-dimensional baroclinic problem of ocean circulation. VTs CO AN CCCR, Novosibirsk, 1972, pp.98-122 (in Russian).
[45] Marchuk G. I., Kordzadze A. A., Zalesny V. B. A Problem of mathematical modeling of sea and ocean currents. In: Differential and Integral equations, Tbilisi, 1979, pp. 99-151(in Russian).
[46] Marchuk G. I., Kordzadze A. A. Numerical modeling of sea dynamics on the basis of splitting method. In: Numerical modeling of climate of the World ocean. OVM AN CCCR, 1986, pp.151-163 (in Russian).
[47] Marchuk G. I. Numerical methods in weather prediction. Leningrad, Gidrometeoizdat, 1967, 356 p (in Russian).
[48] Marchuk G. I. Numerical solution of the problems of atmosphere and ocean dynamics. Leningrad, Gidrometeizdat, 1974, 303p (in Russian).
[49] Stanev E. V., Rusenov V. Numerical modeling of seasonal variability of sea currents. In: Complex global monitoring of the World ocean. Leningrad, Gidrometeoizdat, 1985, pp. 120-129 (in Russian).
[50] Girgvliani A. The Coriolis force parameterization in numerical model of the Black Sea dynamics. J. Georgian Geophys. Soc., 1999, v.4b, pp.15-27.
[51] Girgvliani A. Claculation of the effect of the Bosporus Channel on the Black Sea hydropogi. J. Georgian Geophys. Soc., 1999, v.4b, pp.28-39.
[52] Bryan K. A. A numerical method for the study of the circulation of the World ocean. J. Computational Physics. 1969, v.4, № 3, pp. 347-256.
[53] Zatsepin A. G., Baranov V. I., Kondrashov A. A., Korzh A. O., Kremenetskiy V. V., Ostrovskii A. G., Soloviev D. M. Submesoscale eddies at the Caucasus Black Sea shelf and the mechanisms of their generation. Okeanologiya, 2011, v. 51, № 4, pp. 592-605 (in Russian).
[54] Demishev S. G., Dymova O. A. Numerical analysis of mesoscale peculiarities in the coastal zone of the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 2013, t.49, № 6, pp.655-663 (in Russian).
[55] Kordzadze A., Demetrashvili D. Numerical modeling of inner-annual variability of the hydrological regime of the Black Sea with taking into account of alternation of different types of the wind above its surface. Proceed. of Intern. Conference: A year after Johqanesburg-Ocean Governance and Sustainable Development: Ocean and Coasts – a Glimpse into the Future. Kiev, Ukraine, October 27-30, 2003, pp.495-505.
[56] Kordzadze A. A., Demetrashvili D. I., Surmava A. A. Numerical modeling of hydrophysical fields of the Black Sea under the conditions of alternation of atmospheric circulation processes. Izvestiya RAN, Fizika atmosfery i okeana, 2008, t.44, pp.213-224 (in Russian).

[57] Demetrashvili D. I. Modeling of hydrophysical fields in the Black Sea. J. Georgian Geophys. Soc., 2003, v. 8b, pp.19-27.
[58] Oguz T., Latun V. S., Latif M. A. et al. Circulation in the surface and intermediate layers in the Black Sea. Deep Sea Research, 1993, v.1, №40, pp.1597-1612.
[59] Oguz T., Malanote-Rizzoli P., Aubrey D. Wind and thermohaline circulation of the Black Sea driven by yearly mean climatological forcing. J. Geophys. Res., 1995, v.100, №C4, pp. 6845-6863
[60] Stanev E. V. Understanding Black Sea dynamics: Overview of recent numerical modeling. Oceanography, 2005, v.18, № 2, pp.52-71.
[61] Staneva J. V., Dietrich D. E., Stanev E. V., Bouman M. J. Mesoscale circulation in the Black Sea: New results from DiaCast model simulation. J. Mar. Systems., 2001, v.31, pp.137-157.
[62] Dorofeev V. L., Korotaev G. K. Assimilation of satellite altimetry data in the eddy-resolving model of the Black Sea circulation. Morskoy gidrofisiceskiy zhurnal, 2004, 1, 52-68. (in Russian)
[63] Demishev S. G., Numerical model of operative forecast of the currents in the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 2012, t.48, №1, pp.137-149 (in Russian).
[64] Demishev S. G., Korotaev G. K. Numerical modeling of seasonal course of the synoptical changability in the Black Sea. Izvestiya RAN, Fizika atmosfery i okeana, 1996, t.32, № 1, pp.108-116 (in Russian).
[65] Korotaev G. K., Oguz T., Nikiforov A., Koblinsky C. Seasonal, interannual and mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. J. Geophys. Res., v. 108, NO. C4, 3122, 2003, doi:10.1029/2002JC001508, pp.19-1 – 19-15.
[66] State of the environment of the Black Sea (2001-2006/7). A report by the Commission on the Protection of the Black Sea Against Pollution. 2008-3, Istanbul, Turkey, 419 p.
[67] Titov V. B. About role of vortexes in the forming of current mode on the shelf of the Black Sea and in ecology of the coastal zone. Okeanologia, 1992, t. 32, № 1, pp.39-48 (in Russian).
[68] Korotaev G. K., Dorofeev V. L., Motyzhev S. L., Belokopytov V.N., Palazov A., Malciu V., Zatsepin A.Z., Nesterov E., Stanichny S. V., Ratner Y.B., Suetin V.S., Suslin V. V. Contribution of the Black Sea observing system to ECOOP. Ocean Sciense Discuss., 8, 1695 1722. 2011, www.ocean-sci-discuss.net/8/1695/2011/, doi:10.5194/osd-8-1695-2011.
[69] Korotaev G. K., Oguz T., Dorofeyev V. L., Demyshev S. G., Kubryakov A. I., Ratner Yu. B. Development of Black Sea nowcasting and forecasting system. Ocean Science, 2011, 7, pp. 629-649. doi:10.5194/os-7-629-2011/.
[70] Kubryakov A. I., Korotaev G. K., Dorofeev V. L., Ratner Y. B., Palazov A., Valchev N.,Malciu V., Matescu R., Oguz T. Black Sea Coastal forecasting system. Ocean Science, 2012, 8, pp.183-196.
[71] Gruzinov V. M., Borisov E. V., Grigoriev A. V. Applied Oceanography. Moskva, 2012, 383 p (in Russian).
[72] Marchuk G. I., Paton B. E., Korotaev G. K., Zalesny V. B. Data – computing technologies: A new stage in the development of operational oceanography. Izvestiya RAN, Fizika atmosfery i okeana, 2013, t.49, № 6, pp.629-642 (in Russian).
[73] Kordzadze A. A., Demetrashvili D. I. Some results of forecast of hydrodynamic processes in the easternmost part of the Black Sea. J. Georgian Geoph. Soc., 2010, 14b, p.37-52.
[74] Kordzadze A. A., Demetrashvili D. I. Operational forecast of hydrophysical fields in the Georgian Black Sea coastal zone within the ECOOP. Ocean Science, 2011, 7, pp.793-803, www.ocean-sci.net/7/793/2011/.
[75] Kordzadze A. A., Demetrashvili D. I., Kukhalashvili V. G. Circulation processes in the easternmost part of the Black Sea in 2011-2012. Results of simulation and forecast. J. Georgian Geoph. Soc.,2011-2012, v.15b, pp.3-12.
[76] Kordzadze A. A., Demetrashvili D. I. Coastal forecasting system for the easternmost part of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences. 2012, 12, pp.471-477. www.trjfas.org.
[77] Kordzadze A. A., Demetrashvili D. I. Simulation and forecast of oil spill transport processes in the Georgian Black Sea coastal zone using the regional forecasting system. J. Georgian Geoph. Soc., 2014, v.17b, pp.3-14.
[78] Kordzadze A. A., Demetrashvili D. I. The Black Sea oceanography in the past and at current stage. Tbilisi State University Press, 2017, 187p (in Georgian).

ძირითადი ეტაპები შავი ზღვის ოკეანოგრაფიის ისტორიაში

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რეზიუმე

სტატიაში მოკლედაა აღწერილი ძირითადი ეტაპები შავი ზღვის ოკეანოგრაფიის ისტორიაში შუა საუკუნეებიდან დღემდე. ნაჩვენებია, რომ თანამედროვე ცოდნა შავი ზღვისა და ამ უნიკალური ზღვის აუზში მიმდინარე ჰიდროფიზიკური და ბიოქიმიური პროცესების შესახებ ყალიბდებოდა მრავალი მკვლევარ-ოკეანოლოგების დაუღალავი საქმიანობის შედეგად ბოლო რამოდენიმე საუკუნის მანძილზე. მნიშვნელოვანი ყურადღება ეთმობა თანამედროვე ოპერატიულ ოკეანოგრაფიას თანამედროვე ინფორმაციულ-გამოთვლითი ტექნოლოგიებისა და თანამგზავრული დისტანციური ზონდირების მეთოდების გამოყენებით.

Основные этапы в истории океанографии Черного моря

А. Кордзадзе, Д. Деметрашвили

Резюме

В данной статье кратко описываются основные этапы в истории океанографии Черного моря со средних веков до настоящего. Показано, что современное знание о Черном море и гидрофизических и биохимических процессах, происходящих в этом уникальном морском бассейне, достигнуто в результате упорной деятельности исследователей-океанологов в течение последних нескольких веков. Значительное внимание удаляется современной оперативной океанографии с использованием современных информационно-вычислительных технологий и спутниковых дистанционных методов зондирования.