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Numerical study of the vertical hydrological structure of the Black sea under January atmospheric climatological forcing

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Abstract

This paper is devoted to the analysis of the vertical structure of circulation and thermohaline fields in the Black Sea for January climatic conditions on the basis of a 3-D baroclinic model of the Black Sea dynamics with 5 km resolution. The model makes it possible to take into account wind driven forcing with alternation of different climatic wind fields and the atmospheric thermohaline action by both the Dirichlet conditions through setting the temperature and salinity at the sea surface and the Neumann conditions through setting the heat fluxes, evaporation, and atmospheric precipitation. The analysis of the performed numerical experiment has shown that within the layer with depth 0 - 300 m the sub-layers are forming with variable depth in time due to the simultaneously influence of the nonstationarity of atmospheric circulation and thermohaline processes. Within each sub-layer circulation characteristics practically do not change on a vertical but they undergoes some changes in time.

1. Introduction

The Black Sea because of its specific hydrological structure many decades is the focus of oceanographic researches. It is one of the most well investigated water basin of the World Oean. The theoretical study of many aspects of formation and evolution of 3-D hydrophysical fields in the Black Sea depending on external and internal physical factors are based on different finite-difference models which differ from each other by used coordinate system, methods of solution, grid parameters, parameterisation of turbulence, etc [1-12]. Among these numerical models is a 3-D basin-scale baroclinic z-level model of the Black Sea dynamics developed at M. Nodia Institute of Geophysics [4], which was adapted and successfully tested for the Georgian coastal zone with 1 km resolution within the EU International projects ARENA and ECOOP [5]. This regional model is a core of the regional forecasting system, which in turn is a part of the basin-scale Black Sea Nowcastin/Forecasting System [8].

Despite of the rather high level of our knowledge in hydro and thermodynamic processes in the Black Sea, we consider that some problems concerning hydrological structure of the sea, are not solved completely. For example, among such problems investigation of a vertical structure of the Black Sea hydrological mode is very importance. Such investigations were performed in [3] on the base of the model [4] with 10 km spacing, where was shown that all depth of the sea basin may be consider as consisting of some relatively homogeneous sub-layers. Within each of the sub-layers general circulation processes practically do not change qualitatively by depth, but essentially change from layer to layer.

The present paper may be considered as continuation of investigations performed in [3]. The main goal of this paper is to investigate the temporal variability of the some relatively homogeneous sub-layer within the depth 0-300 m of the Black Sea for January climatic conditions in the inner-annual time scale as demonstration of the simultaneously role of atmospheric circulation and termohaline impact**.**

2. The model description

To achieve the specified goal, we used a 3-D baroclinic prognostic z-level model of the Black Sea dynamics which is developed at the institute of Geophysics [4]. The model equation system is written for deviations of thermodynamic values from their standard vertical distributions. This model takes into account quasi-realistic sea bottom relief, nonstationary atmospheric wind and thermohaline forcing, water exchange with the Mediterranean Sea and inflow of the Danube River, the absorption of short-wave radiation by the sea upper mixed layer, space-temporal variability of horizontal and vertical turbulent exchange.

The model makes it possible to take into account wind driven forcing with alternation of different climatic wind fields and the atmospheric thermohaline action by both the Dirichlet conditions through setting the temperature and salinity at the sea surface and the Neumann conditions through setting the heat fluxes, evaporation, and atmospheric precipitation.

On the sea bottom the velocity components, heat and salt fluxes were equal to zero. On the lateral surfaces, two kinds of boundary conditions are considered: on the rigid boundaries sharing sea from land, components of current velocity, gradients of temperature and salinity normal to the boundary surface are equal to zero; b) on the liquid boundaries connecting the sea with the Bosphorus Strait and the Danube River, values of velocity, temperature and salinity are given on the basis of experimental data.

The coefficients of horizontal turbulent viscosity and diffusion are assumed as functions of the horizontal grid step and horizontal gradients of velocity components consider in [11], vertical turbulent viscosity and diffusion coefficients were chosen constant equal to 50 cm^2s^{-1} and 10 cm^2s^{-1} For a considered non-stationary, nonlinear problem existence [13] and uniqueness theorems of solution are proved [14]. For solution of the problem a two-cycle splitting method was used described in detail in [9, 10].

3. Key model parameters

At implementation of the Black Sea dynamics model [4] we used improved resolution equal to 5 km in both directions, the quantity of points along axes x and y was 225 and 111, respectively. On a vertical the non-uniform grid with 34 calculated levels on different depths: 0, 2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306 . . . 2306 m were considered.

The types of atmospheric circulation for January were taken from [15,16] in which on the basis of processing of observed data for 1946-1962 41 types of atmospheric circulation are established above territory of the Black Sea within one year.

The multiyear monthly means of temperature and salinity at the sea surface for each moth, which were used in the calculation as the Dirichlet conditions, and the depth profiles of the temperature and salinity averaged over the water area were kindly placed at our disposal by A.N. Kosarev and V.S. Tuzhilkin (Department of Oceanology, Geophysical Faculty, and Moscow State University). The main bulk of data were obtained during the period 1955–1994. The data on evaporation and the field of precipitation borrowed from [12] were conveyed from the Marine Hydrophysical Institute (Sevastopol) within the framework of the ARENA international project.

To determine values of parameters connected with absorption of short-wave radiation some articles have been used [17, 18, 19, and 20]. The other parameters had the following values: the gravitational acceleration g = 980 cm^2/s, the average marine water density $\rho_0 = 1 g/cm^3$, the Coriolis parameter $l = l_0 + \beta y$, where $l_0 = 0.95 \cdot 10^{-4} s^{-1}, \beta = 10^{-13} cm^{-1}s^{-1}$, the time step $\Delta t = 1 h$.

4. Results of numerical experiment

In numerical experiment on simulation of January hydrological mode of the Black Sea the integration started on the 1st of January. As initial conditions annual mean climatic fields of current, temperature, and salinity obtained by the same model were used [4]. Wind forcing variability was expressed as the alternation of different types of wind characterized for January conditions [16]. Duration of action of each atmospheric wind type was10 – 60 h, they differed from each other by direction, module, and repeatibility. When one wind type changed to another, a state to close to calm, with a wind speed of 1 m/s and wind direction corresponding to the arithmetic mean between the two consecutive wind direction, took place between these wind types.

The researches presented in this paragraph are continuation of the previous work [3] in case of space resolution 5 km. Thus, researches are performed in case of January atmospheric climatological forcing. Increase of model resolution allows us to determine vertical hydrological structure more precisely and to specify depth and location of the homogenous sub-layers and explore it's strongly variability in cold season.

4.1. The case of January hydrological mode

In order to illustrate the vertical changeability and transformation of the Black Sea circulation during the winter period, we chose the time interval 129-256 h (January), when the circulation was reorganized as shown in Table 1. Fig. 1 shows the fields of wind tangential friction stress at the sea surface corresponding to northeasterly-western (15-20 m/s), eastern wind (10-15 m/s), and north - eastern wind (> 20m/s) indicated in Table 1.

Figs 2, 4-5. Illustrate the evolution of the Black Sea vertical circulation system within the depth 2-306 m during above mentioned time interval.

Table 1. Alternation of wind types during time interval 129-381 hours, (January) and sub-layers' location

Wind direction	**Wind speed, m/s**	**Time interval, h**	**Sub-layers:**
North-western wind	**1**	129-142	**2-136; 136-306**
Northeasterly-western wind	15-20	142-163	**2-12; 16-36;56-136; 136-306**
Northeasterly-North wind	**1**	**163-176**	2-36; 56-136; 136-306
Eastern wind	10-15	176-194	2-12; 12-26; 36-136; 136-306
Northeasterly -Earth	**1**	194-207	**2-86-136; 136-306.**
North-eastern wind	**>20**	207-243	2-8; 12-26; 36-136, 136-306.
North wind	**1**	243-256	2-16; 16-86-136; 136-306

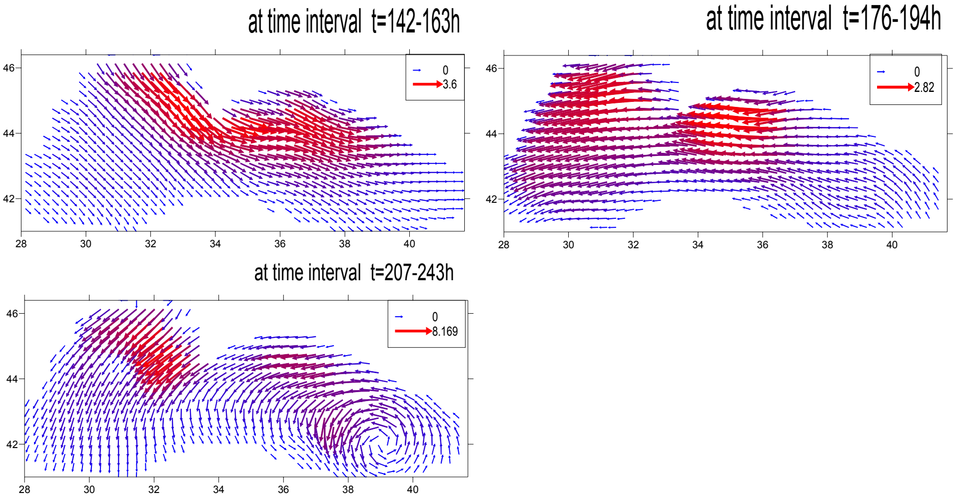

Fig. 1. Vector fields of the wind stress types: Northeasterly- western (15-20m/s), Eastern wind (10-15m/s), North-eastern wind (>20m/s) corresponding (January) to the following time intervals: t= 142-163 h, t = 176-194 h, t = 207-243 h.

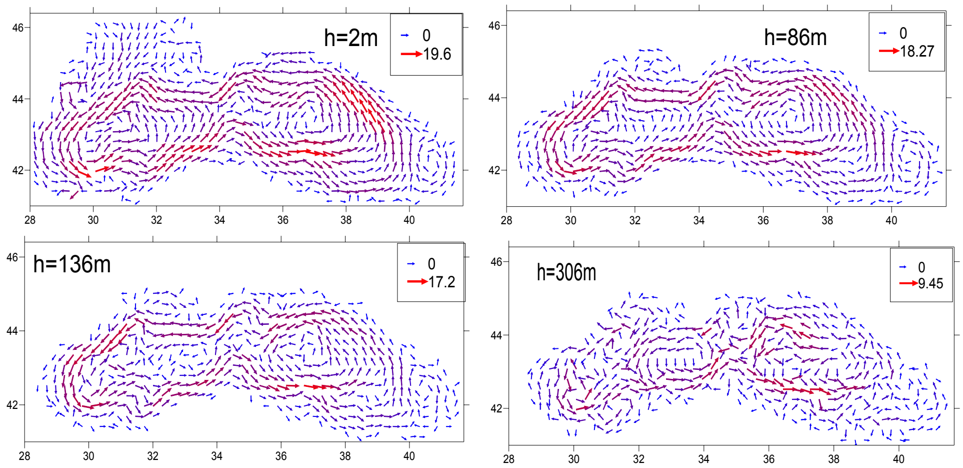

Fig.2. Calculated current field (cm/s) at time t = 142 h (January), according to the North-western wind (1m/s)

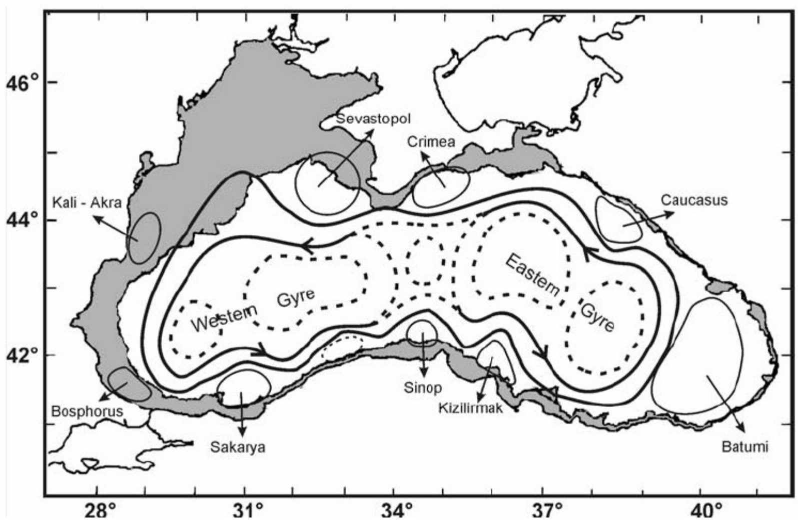

Fig. 3. The Schematic diagram for the main features of the upper layer circulation derived from synthesis of past hydrographic studies prior to 1990.

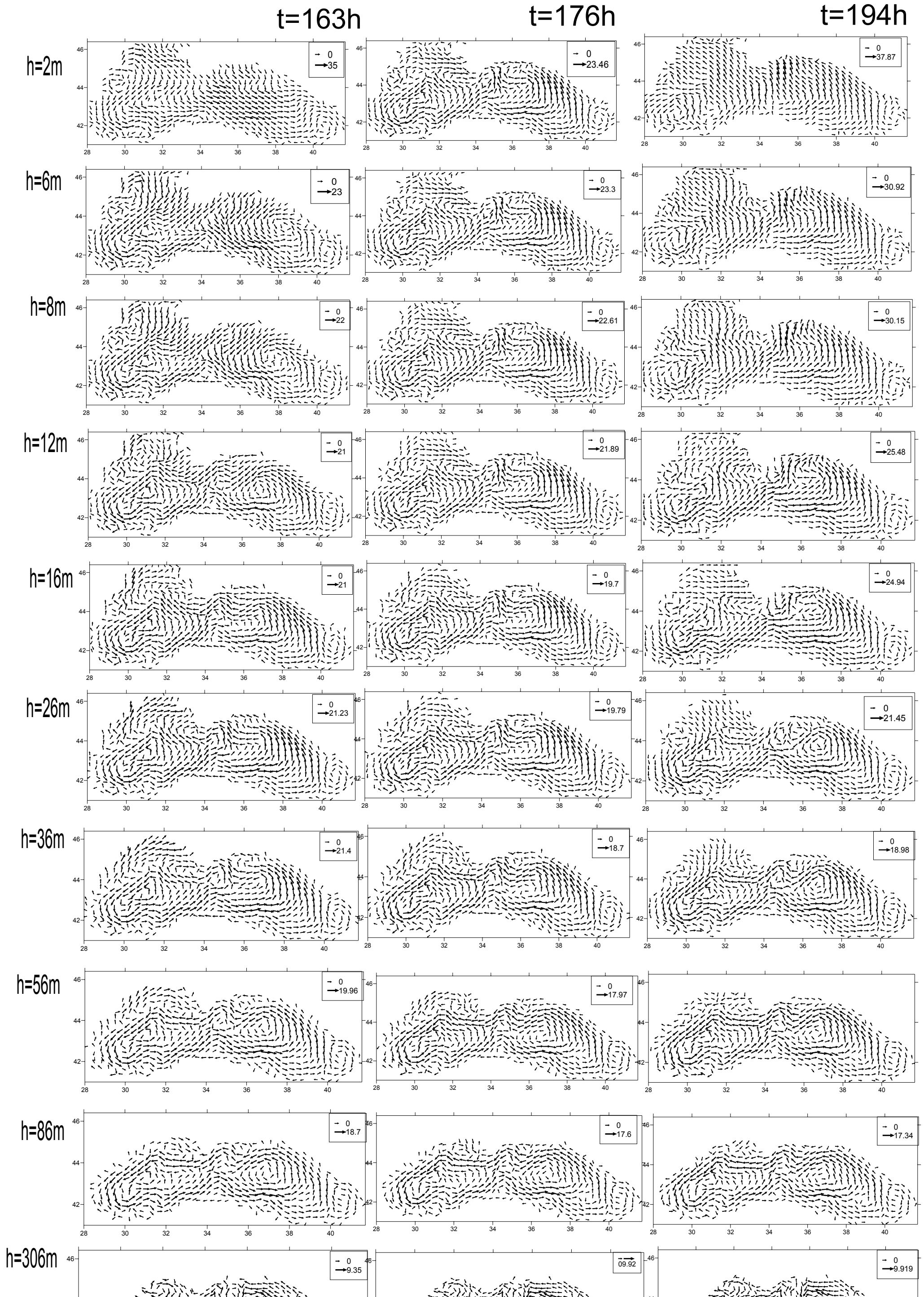

Fig. 4. Calculated current fields (cm/s) at time: t=163h, t=176h, t=194h (January), corresponding to the following wind types: Northeasterly- western (15-20m/s), Northeasterly –North (1m/s), Eastern (10 -15m/s).

Fig. 2 shows computed current fields at the time moment t = 142 h within the depths 0-306 m, when the north-western wind was operated. From the Figure it is visible that generally there are formed two homogenous sub-layers with thickness 1-136 m and 136-306 m, respectively. The level z = 136 m is transition level and so it carries features of both sub-layers. It should be noted that these two sub-layers are forming under conditions, when the atmosphere is close to still conditions and vertical gradients of the velocity and accordingly vertical turbulent mixing process is weak. At that moment maximal velocity of the current on depth of 2 m (it is first calculated level) is < 20 cm/s. This result is in good argument with results known from experimental and theoretical investigations about Black Sea circulation structure [4]. It is interested to note that calculated circulation pattern at moment t = 142 h in the first sub-layer is very similar to the upper layer circulation of the Black Sea obtained from observations (Fig.3) [7].

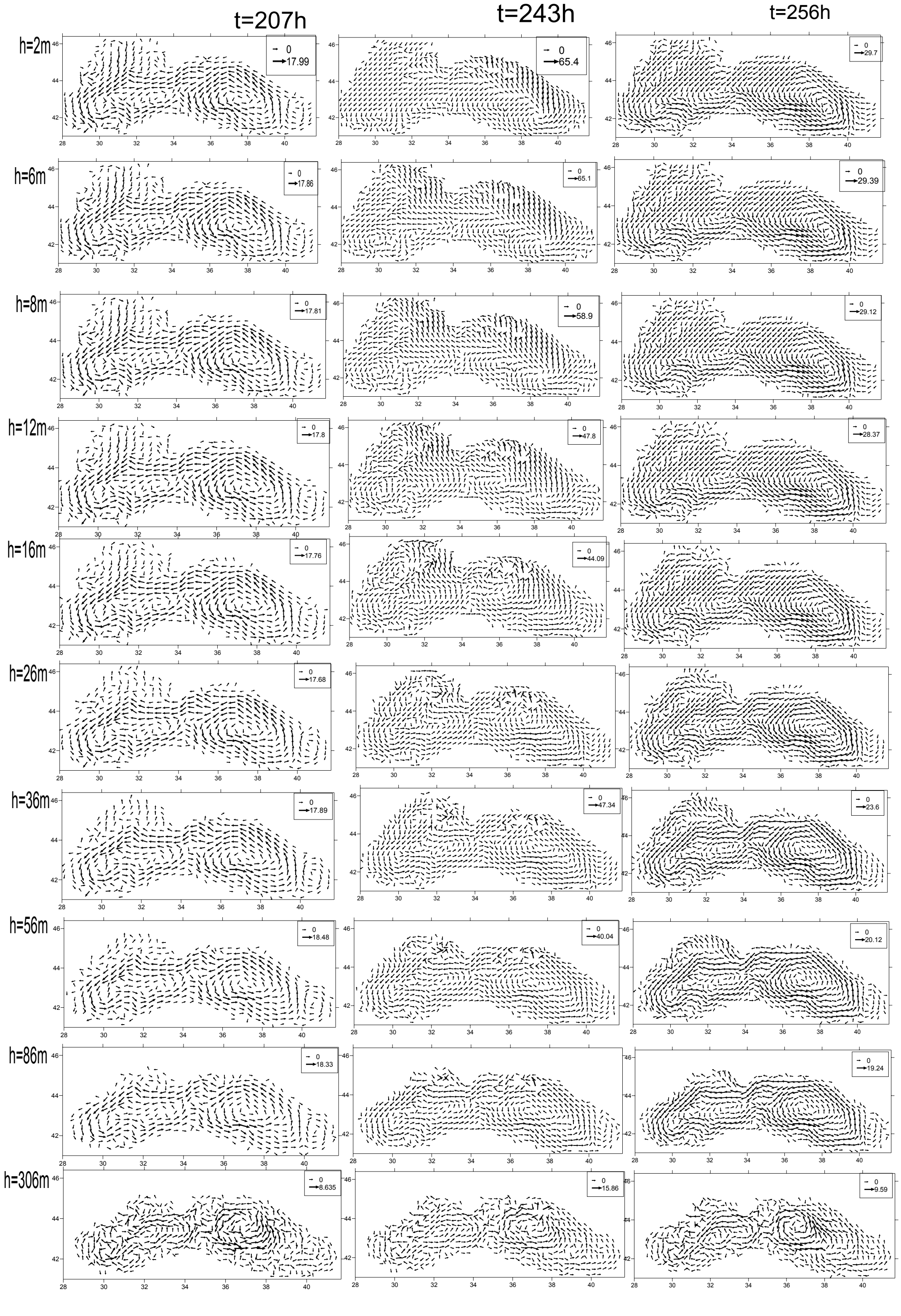

Fig.5. Calculated current fields (cm/s) at time: t=207h ,t=243h, t=256h (January), corresponding to the following wind types: Northeasterly – Eastern (1m/s), North-easterly (>20m/s), and North wind (1m/s).

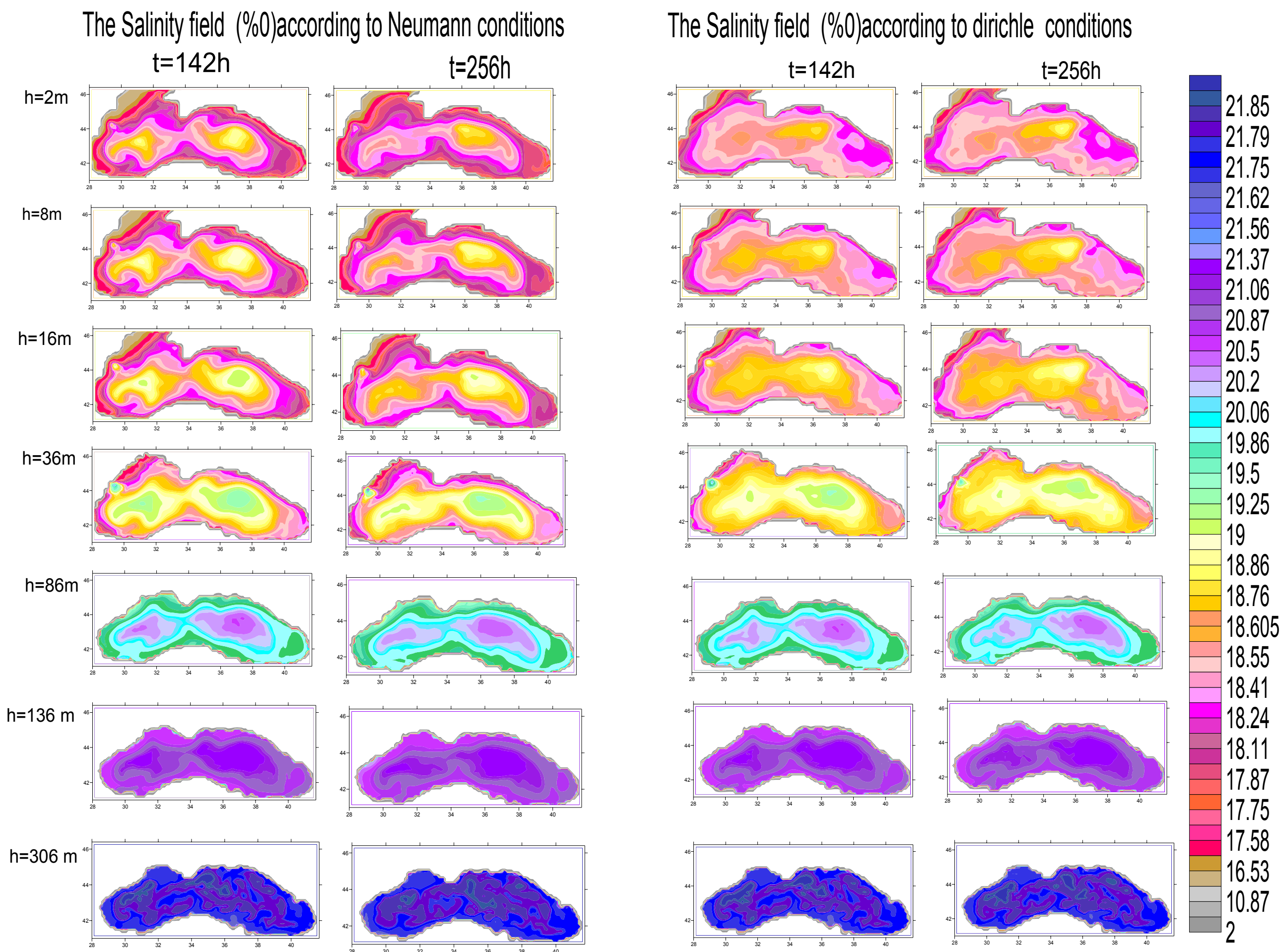

Fig. 6. Calculated salinity field (‰) at time interval t=142-256h, according to Neumann and Dirichlet condition.

In Figs. 4-5 are illustrated formation of vertical structure of sea circulation and its evolution at moments from 163 h to 256 h according to wind driven forcing (Table 1). In case of strong winds at time moments t = 163, 194 and 243 hours in the Black Sea there are formed several sub-layers within layer 0-100 m. It should be noted that despite of calm conditions at time moments t = 176, 256 hours there are observed also several homogenous sub-layers in difference of the first case (Fig.2) and the case at t= 207 (Fig.5). The detail analysis of the results of the numerical experiment has shown that the reason of this fact is the effect of influence of a previous wind. In such cases sea surface current speed > 20 cm/s is observed. The structure of the sub-layers at different wined types is shown also in Table 1.

Fig. 6 shows the salinity fields calculated with using both the Neumann and Dirichlet conditions. Generally, it is well visible that salinity fields are in a good correlation with circulation features. Despite of that the salinity fields in the layer 1-26 m obtained with use of Neumann and Dirichlet conditions differ from each other, sea circulation is the same at any case of boundary conditions. This specifies that in the upper layer of 0-36 m the primary factor of formation of sea circulation vertical structure is wind driven impact in the cold season.

5. Conclusion

Original barolinic 3-D numerical model of the Black Sea dynamics with fine resolution (grid step 5 km) is used to specify homogenous sub-layers structure on a vertical in the upper 0-330 m layer for January climatic conditions.

Analysis of the results of the numerical experiment has shown that, due to the nonstationary atmospheric processes in the Black Sea are forming several homogenous sub-layers with especially features of the circulation. The depth and location of the sub-layers are substantially transforming according to alternation of wind types developed over the Black Sea.

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Численное изучение вертикальной гидрологической структуры Чёрного моря в условиях атмосферного январского климатического воздействия

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Резюме

Работа посвящена анализу вертикальной структуры циркуляции и термохалинных полей в Чёрном море для январских климатических условий на основе трёхмерной бароклинной модели динамики Чёрного моря с 5 км разрешением. Модель даёт возможность учитывать ветровое воздействие с чередованием разных климатических ветровых полей и термохалинное воздействие с помощью условий Дирихле заданием температуры и солёности на поверхности моря и условиями Неймана заданием потоков тепла, испарения и атмосферных осадков. Анализ проведённого численного эксперимента показал, что в Чёрном море внутри слоя с толщиной 0-300 м формируются подслои переменной толщины, обусловленные одновременным влиянием нестационарной атмосферной циркуляции и термохалинных процессов. Внутри каждого подслоя циркуляционные характеристики практически не изменяются по вертикали, но они подвергаются изменениям во времени.

შავი ზღვის ჰიდროლოგიური ვერტიკალური სტრუქტურის რიცხვითი გამოკვლევა იანვრის ატმოსფერული კლიმატური ზემოქმედების პირობებში

დემური ი. დემეტრაშვილი, დიანა. უ. კვარაცხელია, ვეფხია გ. კუხალაშვილი

რეზიუმე

სტატია ეძღვნება შავი ზღვის ცირკულაციისა და თერმოჰალინური ველების ვერტიკალური სტრუქტურის რიცხვით გამოკვლევას იანვრის კლიმატური პირობების გათვალისწინებით 5კმ გარჩევის უნარიანობის მქონე შავი ზღვის დინამიკის 3-განზომილებიანი ბაროკლინური მოდელის საფუძველზე. მოდელი შესაძლებლობას იძლევა გათვალისწინებული იქნას ქარისმიერი ზემოქმედება კლიმატური ქარის ტიპების მონაცვლეობის პირობებში და ატმოსფეროს თერმოჰალინური ზემოქმედება დირიხლეს პირობების მეშვეობით ზღვის ზედაპირზე

ტემპერატურისა და მარილიანობის მოცემით და ნეიმანის პირობებით სითბოს ნაკადების, აორთქლებისა და ატმოსფერული ნალექების მოცემით. ჩატარებული რიცხვითი ექსპერიმენტის ანალიზმა აჩვენა, რომ შავ ზღვაში 0-300 მ სიღრმის ფენაში ყალიბდებიან ერთგვაროვანი ქვეფენები ცვლადი სისქით, რომლებიც განპირობებულნი არიან არასტაციონარული ატმოსფერული ცირკულიაციისა და თერმოჰალინური პროცესების ერთდროული ზემოქმედებით. თითოეული ქვეფენის შიგნით ცირკულაციური მახასიათებლები პრაქტიკულად არ იცვლებიან ვერტიკალზე, მაგრამ ისინი განიცდიან დროში ცვალებადობას.

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