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Numerical Study of the Vertical Hydrological Structure of the Black Sea under Transitive Climatic Forcing Conditions

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ABSTRACT. The paper presents the numerical investigation of the vertical structure of hydrological fields of the Black Sea for transitive (April) climatic conditions. With this purpose a 3-D baroclinic model of the Black Sea dynamics of M. Nodia Institute of Geophysics with consideration of simultaneous influence of the nonstationary atmospheric circulation and thermohaline action by both the Dirichlet and Neumann upper boundary conditions is used. The performed numerical experiment has promoted the primary role of thermohaline impact on the formation of the vertical structure of the Black Sea circulation within the upper 0-306 m layer for transitive climatic conditions. *© 2012 Bull. Georg. Natl. Acad. Sci.*

Key words: *baroclinic circulation, numerical investigation, thermohaline fields.*

Introduction. The changeability of the atmospheric processes developed above the Black Sea basin plays a significant role in the spatial-temporal changes of the hydro and thermo-dynamical parameters in the upper layer of the sea. On the other hand, the hydrophysical processes in the Black Sea directly reflect on the interaction processes between the Black Sea and atmosphere and play a significant role in the formation of the regional weather and climate.

The main goal of this paper is to investigate numerically the temporal variability of the vertical structure of circulation and thermohaline fields within the depth 0-306 m of the Black Sea for transitive seasonal conditions (April) in the inner-annual time scale. This investigation is considered as specification of the special character of the sea circulation, which is formed under the forcing of the external perturbing factors: simultaneous influence of the nonstationarity atmospheric circulation and thermohaline action.

Description of the model. To achieve the specified goal, we used a 3-D baroclinic basin-scale z-level model (BSM) of the Black Sea dynamics [1]. It should be noted that on the basis of the high-resolution regional version [2] of this BSM, the regional forecasting system is developed for the Georgian Black Sea coastal zone with 1 km spacing, which is a part of the basin-scale Black Sea Nowcasting/Forecasting system [2, 3].

The BSM takes into account the 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. Atmospheric forcing is taken into account by boundary conditions on the sea surface considered as a rigid surface.

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 solution domain is covered with grid 225 x 111 having horizontal resolution 5 km. On a vertical the non-uniform grid with 32 calculated levels at depths: 2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306,…, 2206 are considered. The time step is equal to 1 hour.

To solve this problem, we used the two-cycle method of splitting the main problem with respect to both physical processes and coordinate planes and lines [4].

Results of the numerical experiment. In the numerical experiment on simulation of transitive hydrological mode of the Black Sea the integration started on the 1st of January. The annual mean climatic fields of current, temperature, and salinity obtained by the same model were used as initial conditions [1]. Wind forcing variability was expressed as the alternation of different types of climatic wind field characterized over the Black Sea basin [5]. Atmospheric wind types differed from each other by direction, module, recurrence and duration. The duration of action of each atmospheric wind type was between 10–60 hours. 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 directions, took place between these wind types.

The researches presented in this section are a continuation of the previous studies [6, 7], where the vertical hydrological structure of the Black Sea investigated for January atmospheric climatological forcing with 10 and 5 km resolutions, respectively. In [6] it was shown that the entire depth of the sea basin may be considered 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. According to one of the results obtained in [7], atmospheric wind driven forcing plays an important role in the formation of the vertical structure of Black Sea circulation for winter season under both Dirichlet and Neumann upper boundary conditions for temperature and salinity.

In the present paper investigations are carried out for April climatic conditions with 5 km resolution. Besides, both the Dirichlet and Neuman boundary conditions are used to describe atmospheric thermohaline forcing. 5 km horizontal resolvability of the model has allowed us to specify the depth and location of the homogeneous sub-layers and explore their strong variability in a transitive season according to the simultaneous influence of atmospheric circulation and thermohaline impact.

In order to illustrate the vertical changeability and transformation of the Black Sea circulation during the transitive period, we chose the time interval 2684-2836 hours (April, time is accounted from the 1st January), when the atmospheric circulation was reorganized as shown in Table 1.

The same table gives the calculated locations of the homogeneous sub-layers, which are formed within the upper 0-306 m layer of the Black Sea, using both Neumann and Dirichlet conditions describing atmospheric thermohaline forcing.

The results of the numerical experiment show that when the state of the atmosphere is close to calm conditions, the character of sea circulation practically does not change by depth within 0-106 m with the use of both Neumann and Dirichlet bound-

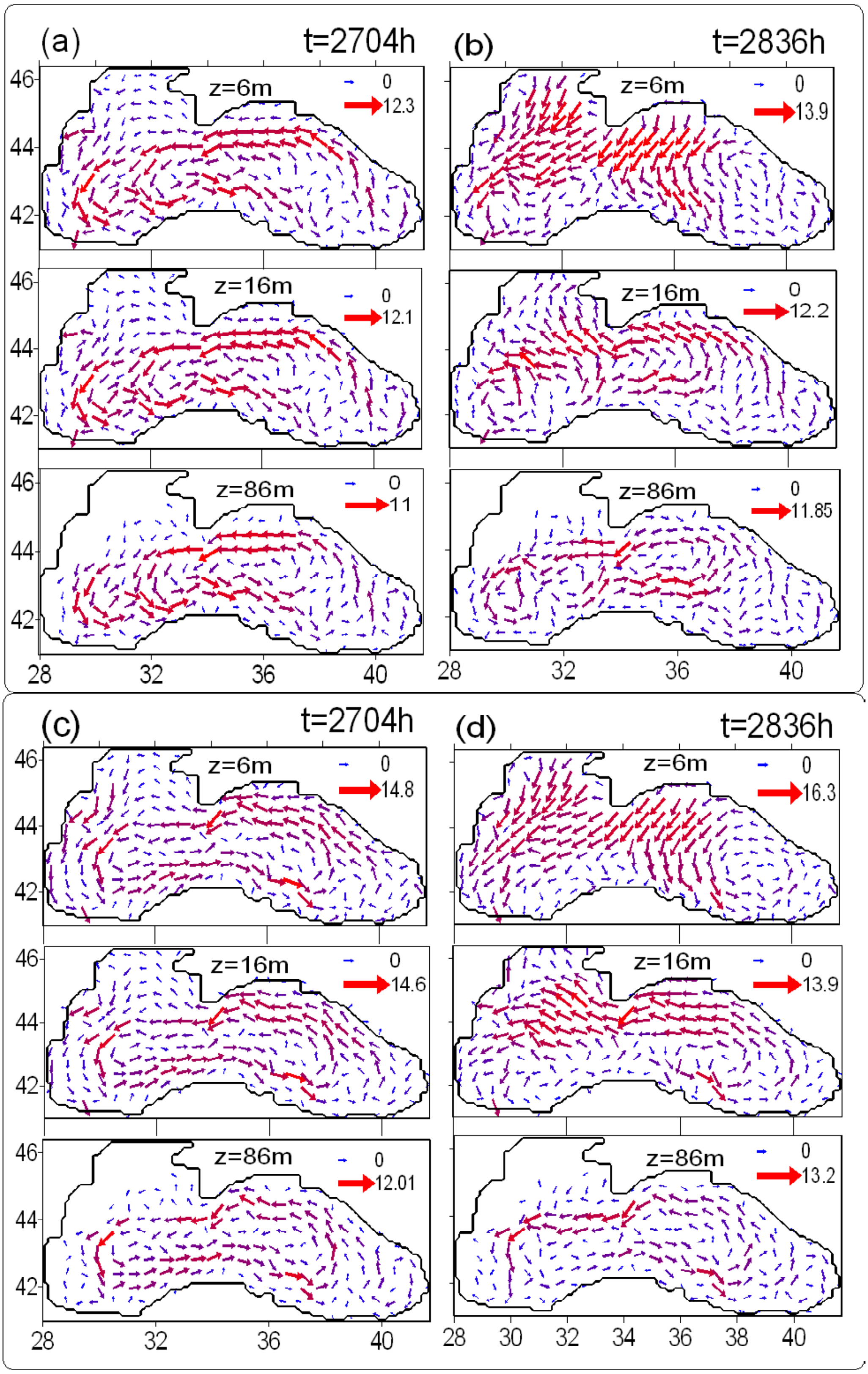

Fig. 1. Calculated current fields (cm/s) at time: t=2704h and t=2836h (April). Fig. 1a and 1b correspond to Neumann conditions, Fig. 1c and 1d correspond to Dirichlet conditions.

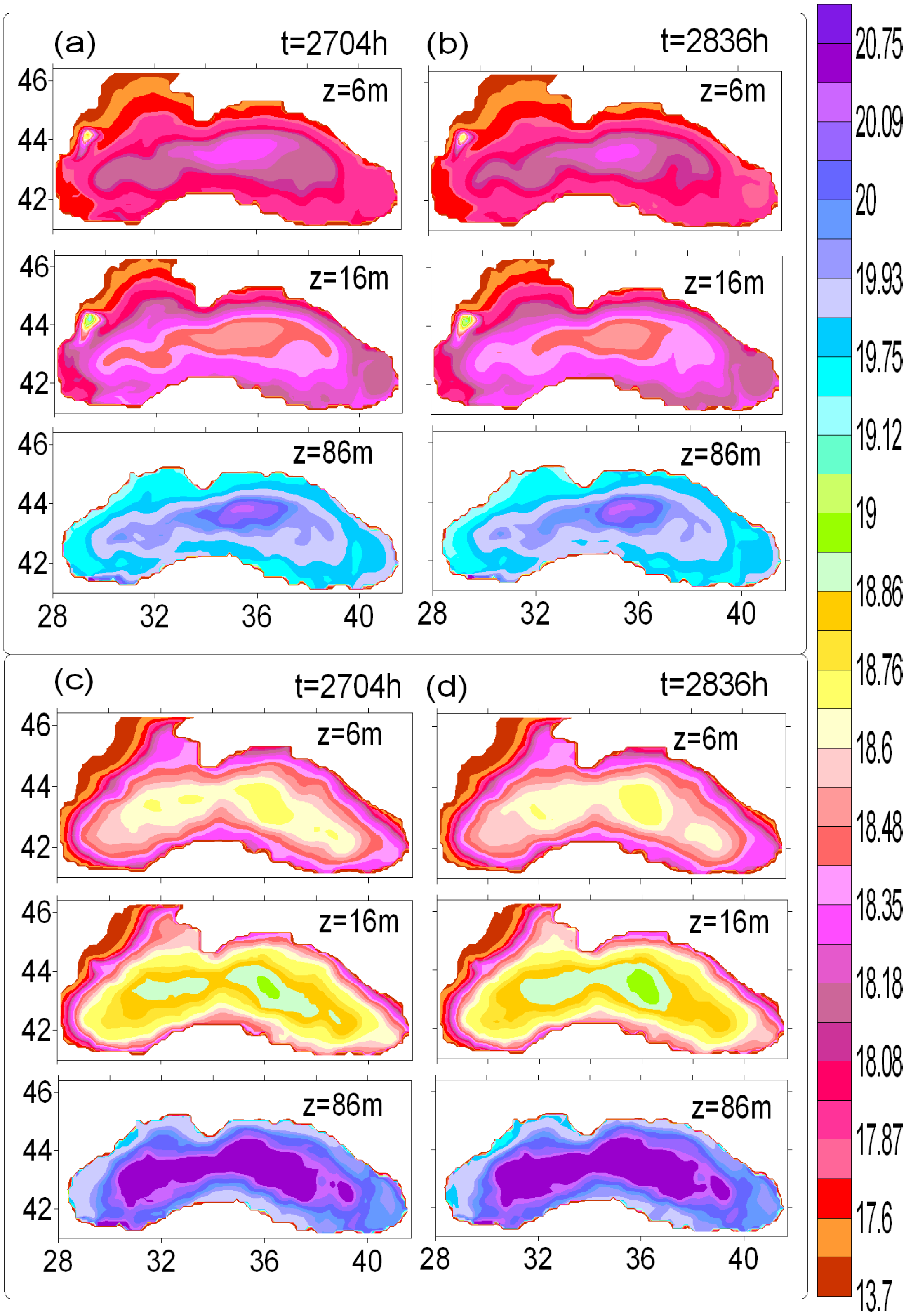

Fig. 2. Calculated salinity fields (‰) at the time t=2704h and t=2836h (April). Fig. 2a and 2b correspond to Neumann conditions, Fig. 2c and 2d correspond to Dirichlet conditions.

Table 1. Alternation of wind types during time interval t= 2704–2836 hours (April) and sub-layers' location between the depth 0 – 306m.

Wind direction	Wind speed, m/s	Time interval, h	Sub-layers depth with both case Neuman and Dirichlet condition
Northwestern - north	1	2684-2704h	2-136m, 136-306m in any case
North-eastern	0-5	2704-2748h	Neum. : 2-136m, 136-306m; Dir.: 2-36, 56-136m, 136-306m.
North-western	1	2748-2772h	2-136m, 136-306m in any case.
Cyclonic	5-10	2772-2796h	Neum.: 2-12, 16- transitive layer , 16-136, 136-306m; Dir.: 2-8, 12 transition layer ,16-136m, 136-306m.
North –western	1	2796-2820h	2-136m, 136-306m in any case.
North- western	5-10	2820-2836h	Neum. : 2-12, 16-transition layer, 16-136 m, 136-306m. Dir. 2-8m; 12-16m, 26-136m, 136-306m.

ary conditions. This fact is clearly observed at t = 2704 h (Fig 1a and 1c) when Northwestern-north wind with speed 1 m/s was operated. The results show also that the circulating patterns received with use of two kinds of boundary conditions qualitatively differ from each other, despite their common feature - homogeneous character of vertical circulation for atmospheric calm conditions. There is a good correlation between circulation (Fig. 1a and 1c) and salinity fields (Fig. 2a and 2c), under both Neumann and Dirichlet conditions.

The observed climatic data show that generally atmospheric winds with 5-10 m/s dominate over the Black Sea during April [5]. In this case two sub-layers are formed within 0-136 m with the use of Neumann conditions and three sub-layers with the use of Dirichlet conditions (see Table 1.). This fact is illustrated in Fig. 1b and 1d, where calculated current fields are shown at t = 2836 h, when the north-western wind with 5-10 m/s operated. The circulation patterns presented in this Figure characterize well the peculiarities of the mentioned sub-layers. In addition, the location of sub-layers practically insignificantly depends on the method of consideration of the atmospheric thermohaline forcing, i.e. on what kind of boundary conditions are used – the Dirichlet or Neumann conditions. The uppermost sea layer with depth about 12 km is more sensitive to wind driven forcing in any case of thermohaline action and is determined by the wind type. In deeper layers below 16 m the influence of atmospheric wind forcing weakens and the structure of circulation (Fig. 1b and 1d) gradually becomes similar to that which was observed in the case of calm atmospheric conditions (see Fig.1a and 1c). This fact shows the primary role of thermohaline forcing in lower layers (see Fig. 2b and 2d respectively). Besides, in any case the level z = 136 m is a transition level and so it carries features of both sub-layers: 1-136 m and 136-306 m.

Conclusion. The numerical experiment carried out with consideration of alternation of atmospheric wind driven forcing and thermohaline action using both the Dirichlet and Neumann conditions has demonstrated the primary role of the thermohaline impact on the Black Sea vertical circulation within the upper 0 - 306 m sea layer for April climatic conditions.

გეოფიზიკა

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

დ. დემეტრაშვილი, დ. კვარაცხელია

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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

სტატია ეძღვნება შავი ზღვის ჰიდროლოგიური ვერტიკალური სტრუქტურის რიცხვით გამოკვლევას გარდამავალი სეზონის (აპრილი) კლიმატური პირობებისათვის მ. ნოდიას გეოფიზიკის ინსტიტუტის შავი ზღვის დინამიკის ბაროკლინური მოდელის საფუძველზე. ატმოსფეროს თერმოჰალინური ზემოქმედება გათვალისწინებულია როგორც დირიხლეს, ასევე ნეიმანის სასაზღვრო პირობებით. რიცხვითმა ექსპერიმენტმა აჩვენა თერმოჰალინური ზემოქმედების პირველადი როლი შავი ზღვის ცირკულაციის ვერტიკალური სტრუქტურის ფორმირებაში აპრილის კლიმატური პირობებისათვის.

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