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Geophysics

Numerical Study of the Influence of Initial Conditions on Thermo-Physical Processes in the Black Sea

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(Presented by Academy Member Tamaz Chelidze)

Abstract. The initialization of the initial state (IS) in the sea dynamics numerical models is one of the important stages, becoming more valuable, when the trend to transition from 10-day forecast to one-month can be seen in the sea and ocean forecasting systems. The aim of this study is to determine two actually different initial conditions (ICs) role on the Black Sea temperature fields and on the upper turbulent layer parameter in dynamics over one month with one-year time interval. The research employs a 3-DH sea dynamics numerical model based on primitive equations, improved with a stable version of the vertical turbulence. The results indicate that in the second year of the model integration, more realistic December data automatic initialization in model provides a better simulated result than at the IS sea hydro-physical average annual fields. Overall, the role of IC at the last day of January compared to the first and tenth days noticeably decreases quantitatively in both the surface and especially sensitive to IC relatively deeper turbulent-mixed layer, located at 56-86 m, which in turn indicates perspective of a one-month forecasting system in future. *© 2025 Bull. Georg. Natl. Acad. Sci.*

Keywords: initial condition, numerical modelling, primitive equations, turbulence

Introduction

As is known, the creation and development of the sea and ocean nowcasting /forecasting systems based on the numerical sea dynamics models are one of the main tools for assessing global climate change. In this paper, our research object is the Black Sea, for which various numerical models have been created since 1998-2005: the ocean general circulation Princeton Ocean Model (POM), DieCast Ocean Model, Hybrid Coordinate Ocean Model (HYCOM) and others (Stanev, 2005). A little later in Georgia, a 3-DH basin-scale numerical model (BS-NM) of the Black Sea dynamics (Kordzadze et. al., 2008) and its high-resolution version for Georgian region (Kordzadze & Demetrashvili, 2011) functioned operationally within the framework of EU projects (Korotaev et al., 2011) was elaborated. To refer all models would take us too far, but it must be said that recently the physics analysis and forecast system of Copernicus marine environment monitoring service (CMEMS) is functionied daily in the Black Sea basin (Jansen et al., 2024; Ciliberti et al., 2022; Kushnir et al., 2019). It should be noted that in Copernicus System, the tendency of transition from a ten – day forecast to one month for the global Ocean can be seen. Besides, based on a recent numerical study (Raileanu et al, 2024), at the mouths of the Danube River in the Black Sea, the extreme wind and wave dynamics are expected in near years (2041-2070). Typically, in operational mode in the Black Sea dynamics model of CMEMS the on-site measured and satellite data are assimilated (Jansen et al., 2024). In turn, at the initial state (IS), in the sea dynamics model, the 3-DH sea current fields, temperature and salinity profiles daily initialization are associated with technological difficulties.

In this paper, based on the BS-NM, the IS influence on the Black Sea temperature fields and turbulence parameter is evaluated with one-year time interval in January. The purpose of the study is to identify the role of initial condition (IC) over the course of one month on the Black Sea thermo-physical fields, which, in our opinion, in future determine a one-month forecasting system activity in the Georgian coastal waters.

Model and Materials

In this study, the Black Sea BS-NM improved with a stable version of the vertical turbulence is used (Kvaratskhelia et al., 2021). It is based on primitive equations system of ocean hydrothermodynamics in the hydrostatic approximation. In the model the upper boundery conditions (no-stationary winds and thermohaline forcing at the sea surface) are determinied by Dirichlet/Neumann conditions using climatic data. In IS, the sea current components (u, v) as well as temperature and salinity deviations $(T' = T - \overline{T}, S' = S - \overline{S})$ are considered as follows:

$$u = u^0, v = v^0, T' = T'^{,0}, S' = S'^{,0}, at\ t = 0, (1)$$

where the mentioned atmospheric climatic fields and sea water temperature and salinity profiles $(\overline{T}, \overline{S})$ belong to the second half of the last century (Kordzadze et. al., 2008). To solve the model equations, a finite-difference scheme based on the splitting method is employed (Marchuk, 1974). Model integration started on 1 January at 12:00 and continued for two years. During model integration, the IC, except on the first day of January, changed automatically, every 2 hours in continuous mode (Marchuk, 1974). Model software and simulated data processing were implemented on the basis of the CV-Fortran 6.1 and Python 3.10.

Results and Discussion

To evaluate the influence of the IS in dynamics on the thermo-physical characteristics of the Black Sea, BS-NM simulated temperature fields are presented with one-year time interval for January 1, 10 and 31, at depth of 0-86m (see, Figs.1 a-c and d-f). It should be noted that in BS-NM, on January 1 during model integration two different ICs are used. More detail: in the first year, in the model as IC the average annual quasi-stationary sea hydro-physical fields were initialized, whereas in the second year, the data of the last 2 hours of December were used automatically.

As shown in Figs.1a-c and d-f, in both cases the sea surface temperatures decreased during January in dynamics. Here, especially in the second year (Fig.1. d-f) the cold waters advection from the north-west into the open waters over the depth of 0-86 meter are observed. This result is in harmony with the forecast product of CREMS (see, Fig.1g, h) which was observed on January 1 and 31 in 2023 (see, https://doi.org/10.48670/mds-00355 and https://marine.copernicus.eu/). In our opinion, common trend of sea surface water cooling is caused by the thermohaline forcing and radiation effects, which are unchanged in both cases, as also the average temperature and salinity profiles.

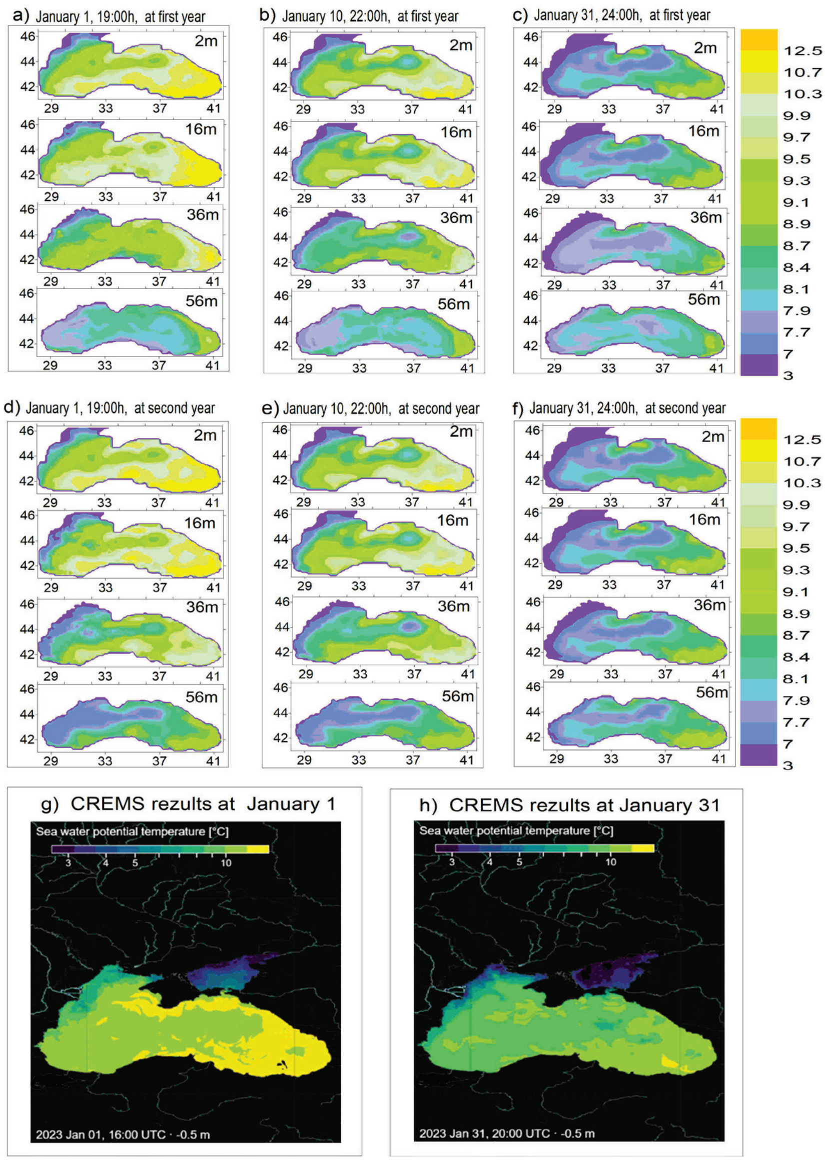

Fig. 1. Simulated sea temperature fields on January 1, 10 and 31 of the first year at depths of 2, 16, 36 and 56m - (a-c), same fields for second year - (d-f) and CREMS results for January 1 and 31, 2023 –(g) and (h).

Besides, on January 1,10 and 31 in both cases the north (5-10 m/s), north-east (>20m/s) and north-west (5-10 m/s) winds activity are considered in the model. They operate during 19, 22 and 24 hours, respectively and the Black Sea currents with internal cyclonic eddies are formed below the Ekman layer (EL), typically approximately from the depths of 12 or 16 m (Demetrashvili et al., 2008; Demetrashvili & Kvaratskhelia, 2012). In turn, the sea currents structure as in the Baltic Sea (Dargahi, 2019) is characterized by multi-layered mechanism of the circulation and vortices. Naturally, the strong vertical gradients of currents in the EL and advection processes (Demetrashvili et al., 2008; Demetrashvili & Kvaratskhelia, 2012; Demetrashvili et al., 2022) play a significant role on the sea temperature fields and configuration of Mixed layer (ML).

Besides this, here sea temperature fields with one year time interval, as well as in previous work (Kvaratskhelia & Demetrashvili, 2024), radically different at January 1, approximately from depth of

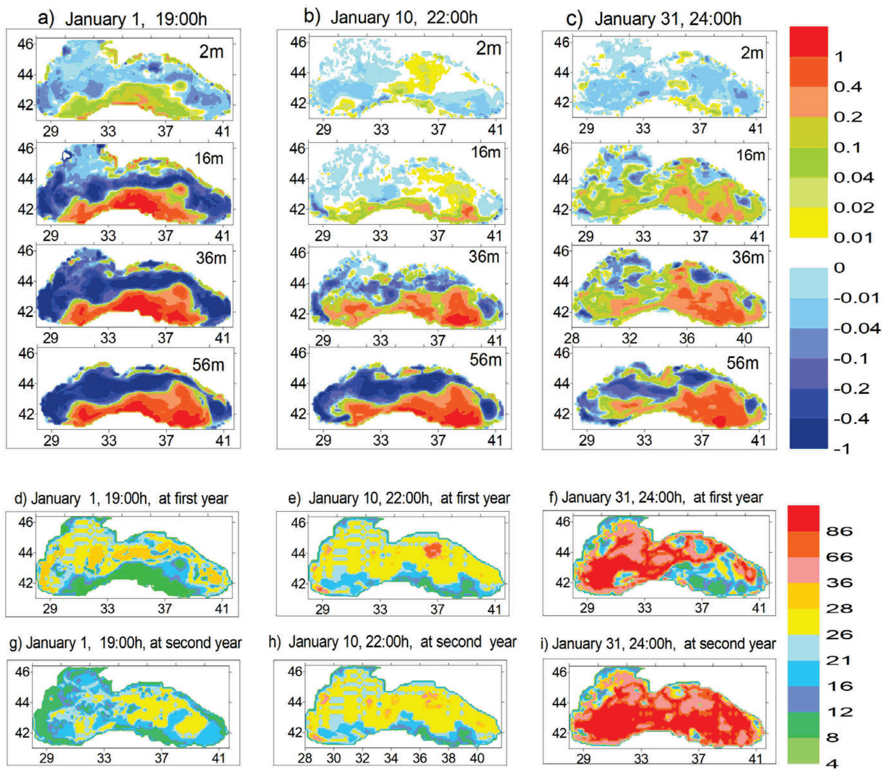

Fig.2. Differences in the sea temperature fields, at one-year interval on January 1, 10 and 31, at depths of 2, 16, 36, 56 m – (a-c); ML depth horizontal fields for first year – (d-f), and the corresponding same fields for the second year – (g-f).

16 meter (Fig.1a and Fig.1d). Difference in the temperature fields is gradually decreased and in dynamics it is observed from a depth of 36 and 56 m for January 10 and 31 (Fig.1b,c and Fig.1d,e). This process caused by IC, a more clearly is observed in the quantitative difference of the temperature fields (see, Fig.2 a-c). More detail: the quantitative difference, which in range of $-0.2^0\text{C} < \Delta T < 0.2^0\text{C}$ is fixed in first day on the sea surface, gradually decreased $(-0.04^0\text{C} < \Delta T < 0.04^0\text{C})$ for January 10 and 31. This difference, in dynamics is decreased not only in the surface waters, but also at a depth of 36-86 m. In addition, it is clear, the cooling process after one year in dynamics more intensity covers in the deep waters of the north and north-west regions (Fig. 2 a-c), while in the south and in south-east sea regions a more warm waters (Ratner & Korotaev, 2017) are fixed, typically.

At the same time, in Fig. 2 d-i the horizontal depths of turbulent mixed layer (ML), which as in previous work (Kvaratskhelia et al., 2021) estimate with the temperature criterion ($|\Delta T| \leq 0.2^0\text{C}$) are given. As is known, turbulent mixing importantly defines the heat supply to the atmosphere. Based on this study, in January the ML depth grows in dynamics (See, Fig. 2 f, i). Its structure with one-year time period significantly differs from each-other for January 31, which once again confirms IC role in deep water, at the depth of ~56-86 m, in which quantitative difference between temperature fields despite reduction (Fig. 2 a-c) are more than 0.2^0C. In addition, in contrast to other studies (Kara et al., 2009; Jansen et al., 2024; Stanev & Chtirkova, 2021), ML maximal depth is revealed in the south and south-eastern region of the sea basin (see, Fig. 2i). In our opinion, this is related to the fact that in this paper the ML is analyzed based on one of its characteristics – the sea temperature fields, which are evaluated using the absolute value of the temperature criterion (0.2^0C).

Conclusion

The numerical studies presented in this paper show that IC influence on the sea temperature fields is insignificant especially in the surface waters, as far as in same areal the boundary conditions and turbulent exchange process define mainly sea water state (Demetrashvili & Kvaratskhelia, 2012; Kvaratskhelia et al., 2021). In contrast, in deep waters IC role is more noticeable both on the quantitative difference of the sea temperature fields and in horizontal fields of the turbulent – ML depth. Besides, after one year, automatic initialization of December data in the model, which defines the Black Sea temperature fields more close to real one, shows necessity of the IS adequate initialization. In overall, IC role in dynamics at last day of January noticeably small, than on the first and ten days, which indicates one-month forecasting system perspective for Georgian sea waters, using high-resolution – version of the BS-NM.

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შავი ზღვის თერმოფიზიკურ პროცესებზე საწყისი მდგომარეობის გავლენის რიცხვითი შესწავლა

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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

ზღვის დინამიკის რიცხვით მოდელებში საწყისი მდგომარეობის (სმ) ინიციალიზაცია ერთ-ერთი მნიშვნელოვანი ეტაპია, რომელიც კიდევ უფრო ღირებული ხდება, როდესაც ზღვისა და ოკეანის პროგნოზირების სისტემებში 10-დღიანი პროგნოზიდან ერთთვიანზე გადასვლის ტენდენცია შეინიშნება. კვლევის მიზანია შავი ზღვის ტემპერატურის ველებსა და ზედა ტურ-ბულენტური ფენის პარამეტრზე ორი რეალურად სხვადასხვა საწყისი პირობის (სპ) ზეგავ-ლენის დადგენა დინამიკაში ერთი თვის განმავლობაში, ერთწლიანი დროითი ინტერვალით.

კვლევა ჩატარდა პრიმიტიულ განტოლებებზე დაფუძნებული ზღვის დინამიკის 3-DH რიცხვითი მოდელის გამოყენებით, რომელიც გაუმჯობესებულია ვერტიკალური ტურბულენტობის სტაბილური ვერსიით. როგორც ეს კვლევა აჩვენებს, მოდელის ინტეგრირების მეორე წელს, მოდელში უფრო რეალური დეკემბრის მონაცემების ავტომატური ინიციალიზაცია უკეთეს შედეგს იძლევა, ვიდრე საწყის მდგომარეობაში, ზღვის ჰიდროფიზიკური საშუალოწლიური ველების ინიციალიზაცია. საერთო ჯამში, იანვრის ბოლო დღისთვის სპ-ის როლი პირველ და მეათე დღეებთან შედარებით, ნებისმიერ შემთხვევაში შესამჩნევად მცირდება რაოდენობრივად, როგორც ზედაპირულ, ასევე სმ-ის მიმართ განსაკუთრებით მგრძნობიარე, შედარებით ღრმა ტურბულენტურ-შერეულ ფენაში, რომლებიც 56-86 მეტრზეა განლაგებული, რაც, თავის მხრივ, ერთთვიანი პროგნოზირების სისტემის პერსპექტივაზე მიუთითებს მომავალში.

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