Some results of forecast of hydrodynamic processes in the easternmost part of the Black Sea

Avtandil A. Kordzadze, Demuri I. Demetrashvili

Iv. Javakhishvili Tbilisi State University, M. Nodia Institute of Geophysics, 1,Alexidze Str., 0173, Tbilisi, Georgia, e-mails: akordzadze@yahoo.com, demetr_48@yahoo.com

Abstract

Regional forecasting system to predict currents, temperature and salinity 3-D fields for the easternmost part of the Black Sea have been developed within the context of the international scientific-technical EU projects ARENA and ECOOP. The regional area is bounded with the Caucasus and Turkish shorelines and the western liquid boundary coinciding with 39.36^0E. A core of the forecasting system is the highly resolving 3-D regional prognostic model of the Black Sea dynamics developed at M. Nodia Institute of Geophysics. The regional model with 1 km spacing is nested in the basin-scale model of the Black Sea dynamics (with the grid step 5 km) of Marine Hydrophysical Institute (MHI, Sevastopol/Ukraine). All input data required for 4-days forecasts are regularly obtained from MHI via Internet. At present the system is ready for operational functioning.

1. Introduction

For the last decades researches on dynamics of the Black Sea have received wide development. Attraction of new technologies of observations including satellite methods of measurement [1-3], creation of highly resolving mathematical models allowing to reproduce dynamic processes by sufficiently high adequacy [4-11] have lifted on higher level oceanography of the Black Sea. Our knowledge and understanding of hydrodynamic processes of the Black Sea, became more perfect and traditional opinion about character of averaged surface circulation of the Black Sea [12,13] has considerably changed. Nowadays, it is possible to present character of the general circulation of the Black Sea as follows: as a whole, circulation of the upper layer has cyclonic character and main component of this circulation is the meandering Rim Current, which amplifies and stabilized during the autumn-winter period. The Rim Current represents a jet stream with width 40-80 km and average speed of 20-25 cm/s on its axis passing on peripheries of the basin counterclockwise. Characteristic features of the general circulation are also existence of two or more cyclonic gyres in the open part of the sea and the coastal anticyclonic eddies connected with meandering of the Rim Current. Among anticyclonic eddies formed in the east part of the basin, the Batumi eddy located in the southeast part is rather steady formation during warm season [11, 14]. Weakening of atmospheric circulation and prevalence of windless weather promote vortex formations in the surface layer, whereas strong winds have smoothing action and promote the breakup of vortical formations [14,15]. At strong wind speeds sea current can reach or surpass 100 cm/s [16, 17].

Thus, as a result of improvement of our knowledge on physical processes in the Black Sea, improvement and working out new observation systems and highly adequate models of dynamic processes of the Black Sea, on a threshold of current century has ripened necessity to create a Nowcasting/Forecasting Operative System of the Black Sea state, which allows to observe current distribution of the physical parameters characterizing a condition of the sea basin and to predict their evolu-

tion to some days forward, i.e. to carry out the continuous control over the state of the Black Sea [3]. Functioning of such system especially important for coastal and shelf areas which undergoes to the greatest anthropogenous loadings.

The important stage for solution of this main problem of modern operative oceanography was the work carrying out by the leading oceanographic Centers of Black Sea riparian countries: Bulgaria, Georgia, Russia, Romania, Turkey and Ukraine within the frame of EU international scientific-technical project ARENA [18, 19]. Coordination of this work was carried out by Marine Hydrophysical Institute (MHI, Sevastopol) of National Academy of Science of Ukraine. For the first time in practice of the Black Sea oceanography a pilot experiment on functioning of Nowcasting/Forecasting System of the Black Sea state in the near-real time mode has been carry out during 22-26 July 2005. In this experiment the regional model of dynamics of the Black Sea developed at M. Nodia Institute of Geophysics has been used for 2 days forecasts of currents, temperature, and salinity in the narrow part of the Georgian sector of the Black Sea including Batumi, Poti and Sokhumi ports [20, 21].

All input data required for calculation of regional forecasts with high resolution (1 km spacing) were operatively transferred via the Internet from MHI. Using a method of nesting modeling, on the liquid boundary passing along 41^0E and limiting the part of Georgian coastal zone from other part of the sea basin, values of hydrophysical parameters predicted by basin-scale model (BSM) of the Black Sea dynamics of MHI were applied. The analysis and comparison of results of the forecasts to the observational data have shown ability of our regional model to reproduce really hydrophysical fields in the Georgian coastal zone [19]. In further, within the framework of other EU international project ECOOP (2007-2010), for the purpose of reception more perfect regional circulation patterns, the forecasting area has been considerably expanded to the western direction that has allowed to receive more perfect patterns of regional circulation in the most east part of the Black Sea.

At present, calculations of 4-days forecasts of main hydrophysical fields in the expanded area, which is limited by Caucasus and Turkish coastal lines and the liquid boundary coinciding with 39.36^0E, are regularly carry out. All necessary input data we receive regularly from MHI via ftp site.

The purpose of this study is to demonstrate calculation of marine forecasts by regional modeling system for the easternmost Black Sea and to analyze some results of the forecast corresponding to July, 2010.

2. Regional Modeling System for Marine Forecast

A core of a regional modeling system is the nested regional hydrostatic numerical model of the Black Sea dynamics. The model is based on a primitive equation system of ocean hydro-thermodynamics, which is written in z coordinates for deviations of thermodynamic values from their standard vertical distributions [20, 21]. This regional model (RM-IG) is received by adaptation of the basin-scale model (BSM) of the Black Sea dynamics developed at M. Nodia Institute of Geophysics [14, 15] to the easternmost part of the basin and is nested in the BSM of MHI. It is necessary to notice that in turn the BSM of M. Nodia Institute of Geophysics is an improved version of the prognostic model of the Black Sea dynamics [22-26] originally developed in the early 1970s at the Computing Center of Siberian Branch of the Academy of Sciences USSR (Novosibirsk, Akademgorodok).

The regional nested model takes into account absorption of solar radiation by the sea upper layer and spatial-temporal variability of turbulent viscosity and diffusion. Atmospheric forcing is taken into account by boundary conditions on the sea surface z = 0 considered as a rigid surface, where the wind stress components are given as known functions, for temperature and salinity the Neumann conditions are used by given of heat fluxes, evaporation and atmospheric precipitations. On the sea bottom the velocity components, heat and salt fluxes are equal to zero. On the rigid lateral boundaries, shearing the sea basin from land, horizontal components of current velocity, gradi-

ents of temperature and salinity normal to boundary surface are equal to zero. On the liquid boundary, horizontal components of velocity, temperature and salinity predicted by BSM of MHI are used.

The existence and uniqueness theorems of 3D nonstationary problem of sea dynamics are established in [27- 31]. For solving this problem, we used the two-cycle method of splitting the model equation system with respect to both physical processes and coordinate planes and lines, which was proposed by G. I. Marchuk for solution of problems of ocean and atmosphere dynamics [32-35]. This method substantially simplifies the implementation of complex physical model and enables us solution of 3D nonstationary problems to reduce to solution of more simple 2D and 1D problems.

The regional domain was covered with grid 193x347 having horizontal resolution 1 km. On a vertical the non-uniform grid with 30 calculated levels on depths: 1, 3, 5, 7, 11, 15, 25, 35, 55, 85, 135, 205, 305, …, 2005 m were considered. The time step was equal to 0.5 h.

The methodology of nested modeling and forecast is described in [20]. Input data with one hour step corresponding to 4 - days forecasting time period received from MHI are following:
- 3-D fields of temperature, salinity and sea current velocity components including initial fields at moment t = 0;
 - Wind stress components, heat fluxes, evaporation and precipitation on the sea surface.

Data received from MHI correspond to our regional area and are given on a coarse grid of BSM of MHI (with grid step 5 km). Data on the sea surface are prognostic fields calculated from the Atmosphere dynamics model ALADIN; 3D fields of temperature, salinity and velocity components are prognostic fields calculated with use of BSM of MHI.

3. Forecast of Regional Processes, July 2010

Here are presented some results of 4-days forecast of sea processes in the regional area including Georgian sector of the Black Sea (the liquid boundary coincides with 39.36^0E) for the following forecasting time period: 18 July 2010, 00:00 h – 22 July 2010, 00:00 h.

In Fig.1 are presented prognostic wind stress fields on the sea surface for the regional area at some time moments within forecasting time interval. These fields were used for the upper boundary condition to describe wind driven forcing and enable us to discuss about changeability of wind over the allocated area during the forecasting period. It is clear from the Figure that atmospheric circulation during 18 – 22 July 2010 was characterized by significant variability above the easternmost part of the Black Sea. At the initial time of forecast, i. e., on 18 July 2010, 00:00 h the dominated wind direction was absent and atmospheric circulation had complex character (Fig.1a), after 24 hours circulation was sharply transformed to the eastern wind which gradually deviated in a northwest direction over the most part of the sea surface (Fig.1b). Further, the wind continued to change permanently and was gradually transformed to the western wind (Figs.1e and 1f).

Figs.2-4 illustrate the Black Sea circulation, temperature, and salinity fields at initial time of forecast on different horizons. From Fig.2 it is clear that the main element of regional circulation is Batumi anticyclonic eddy, which covers the area with diameter about of 100-120 km. This vortex practically does not change in the upper 200 m layer, only current speed decreases from maximal value equal to 34 cm/s till 12 cm/s. Below 200 m the vortex gradually decreases in sizes (see, Fig. 2e) and on the depth of 1000 m it is not observed any more (see, Fig. 2f).

The analysis of circulation patterns on horizons shows that all depth of the sea may be consider as consisting of some homogeneous sub-layers; in each of them the circulation pattern practically does not change by depth. It should be noted that such steepness vertical structure of circulation was also observed in numerical experiments on simulation of basin-scale circulation of the Black Sea in case of some wind types [36].

Temperature field at the initial time moment is characterized by significant qualitative and quantity changes with depth (Fig. 3). A cold intermediate layer (CIL) occurs on horizons of 50 and 100 m (CIL is bounded with isotherm of 8^0C), but it does not cover all the area (Figs.3c and 3d).

General feature of salinity field is that the area of relatively low salinity coincides with allocation of Batumi anticyclonic eddy (compare, Figs.2 and 4). It is easy to explain this fact to that descending streams which develop in the anticyclonic vortex, transfer less salty waters from the upper layer downwards. In deep layers the temperature and salinity are highly homogeneous in horizontal direction (see, Figs. 3f and 4f), this property is well known for the Black Sea [26, 37].
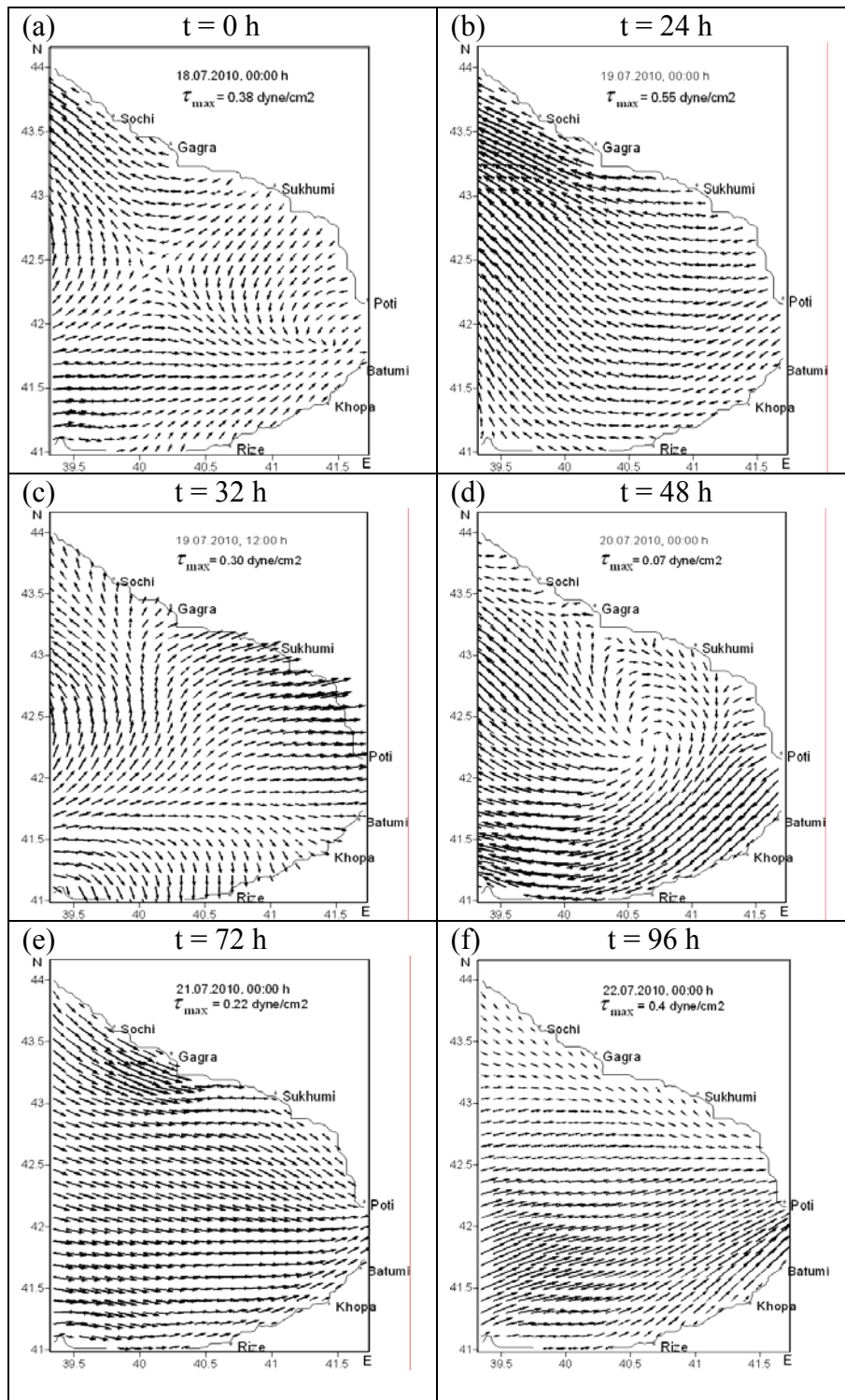

Fig.1. Vector fields of the wind stress on the sea surface within forecasting period:
18.07.2010, 00:00 ч – 22.07.2010, 00:00 ч. (a) – t = 0 h, (b) - t = 24 h, (c) - t = 36 h, (d) - t = 48 h, (e) - t = 72 h, (f) - t = 96 h. (Here and in following Figures time is counted from the initial moment of the forecast).
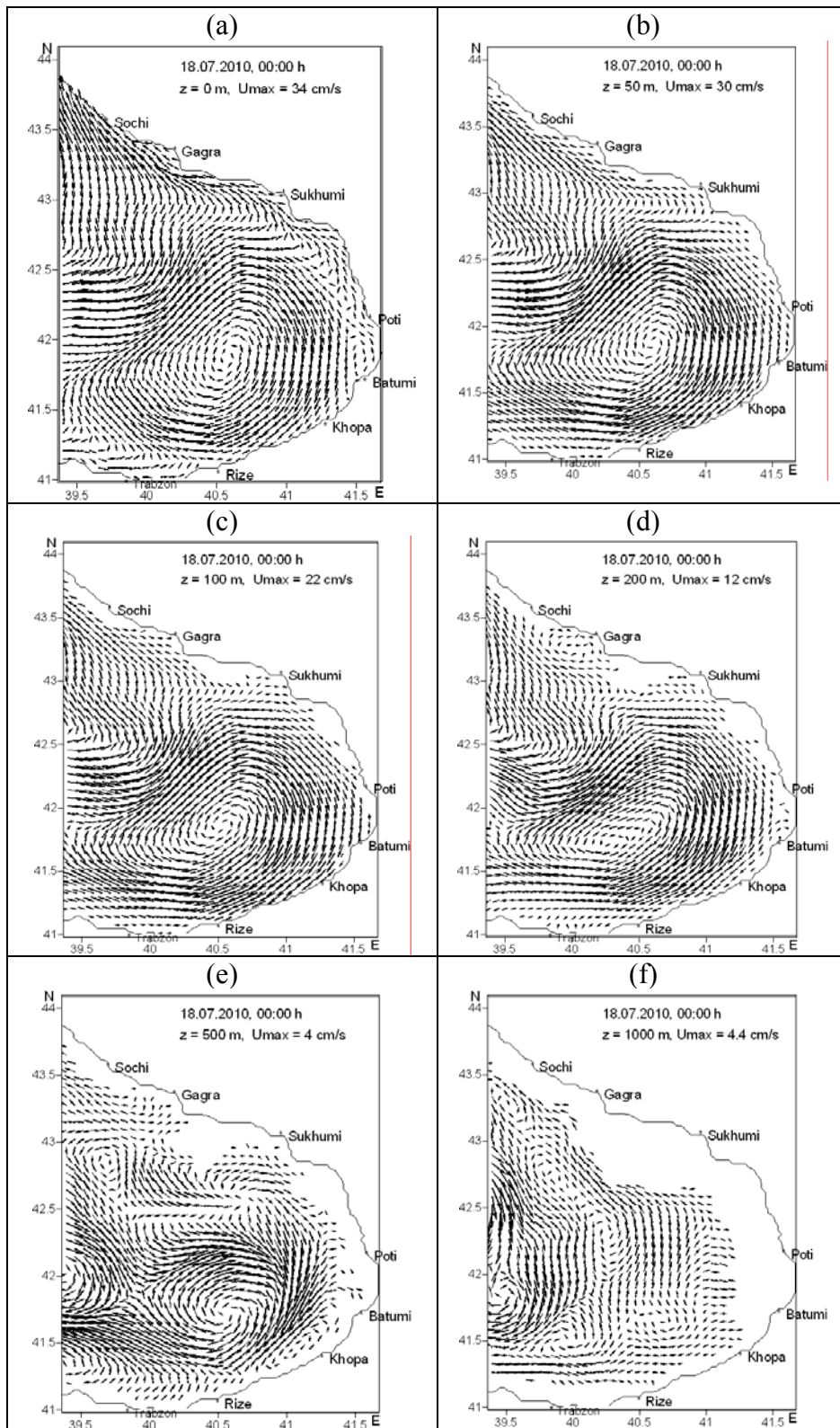
Fig.2 . The current field at the initial time of forecast on depths of (a) 0 m,   (b) 50 m, (c) 100 m,
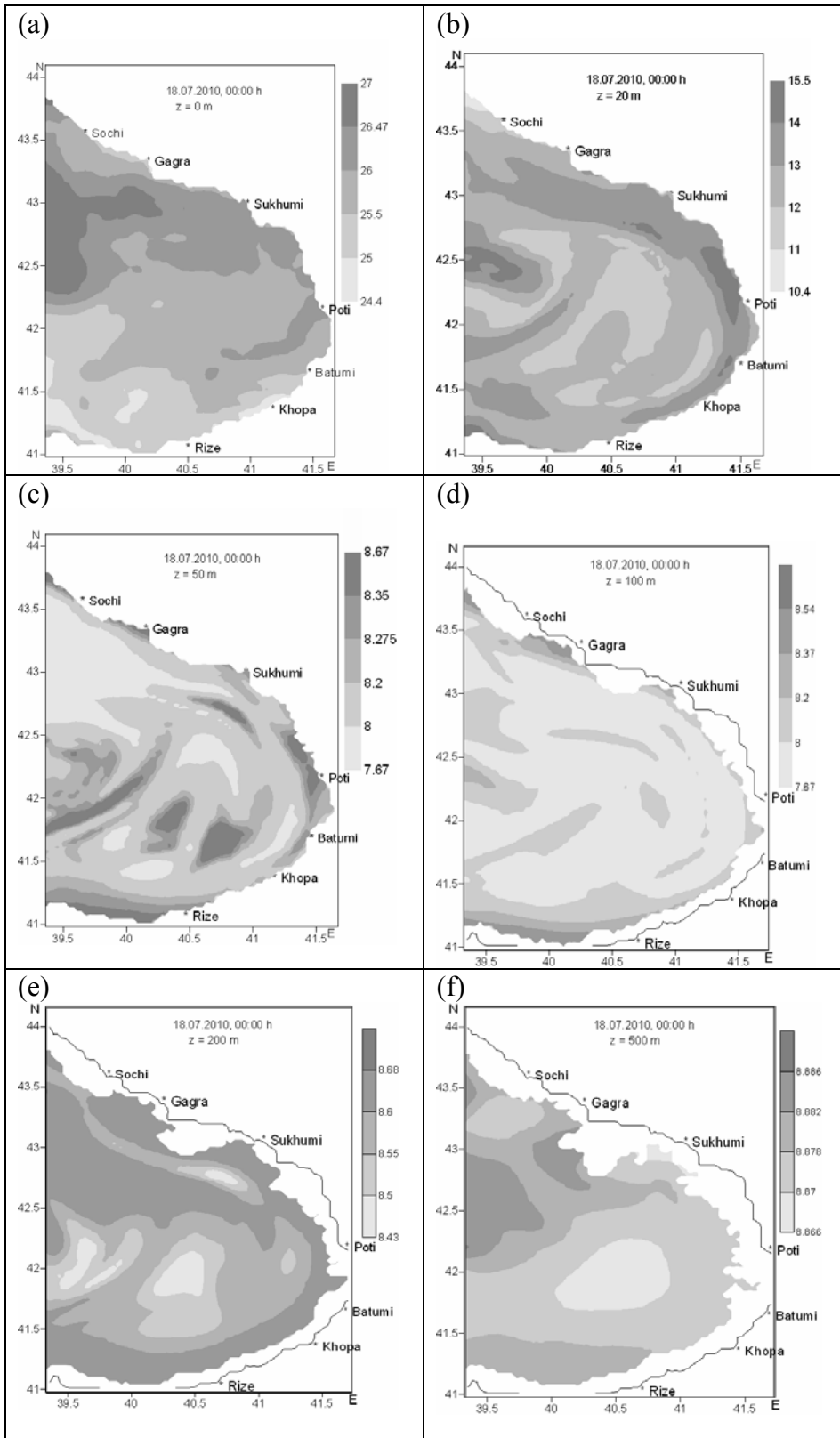   (d) 200 m, (e)   500 m,   (f) 1000 m.

Fig.3. The temperature field at the initial time of forecast on depths of
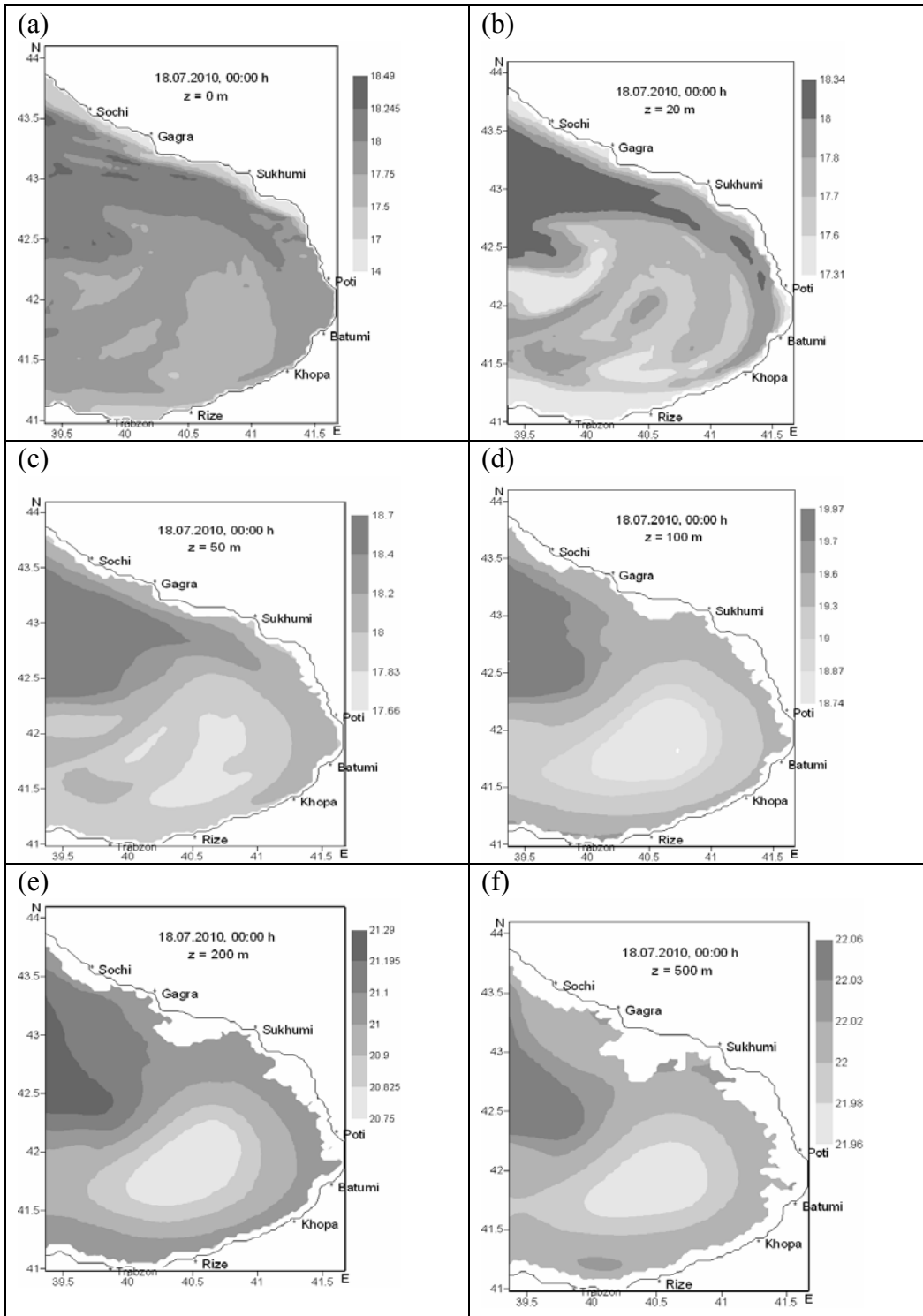(a) 0 m, (b) 20 m, (c) 50 m, (d) 100 m, (e) 200 m, (f) 500 m.

Fig.4. The salinity field at the initial time of forecast on depths of (a) 0 m, (b) 20 m, (c) 50 m, (d) 100 m, (e) 200 m, (f) 500 m.
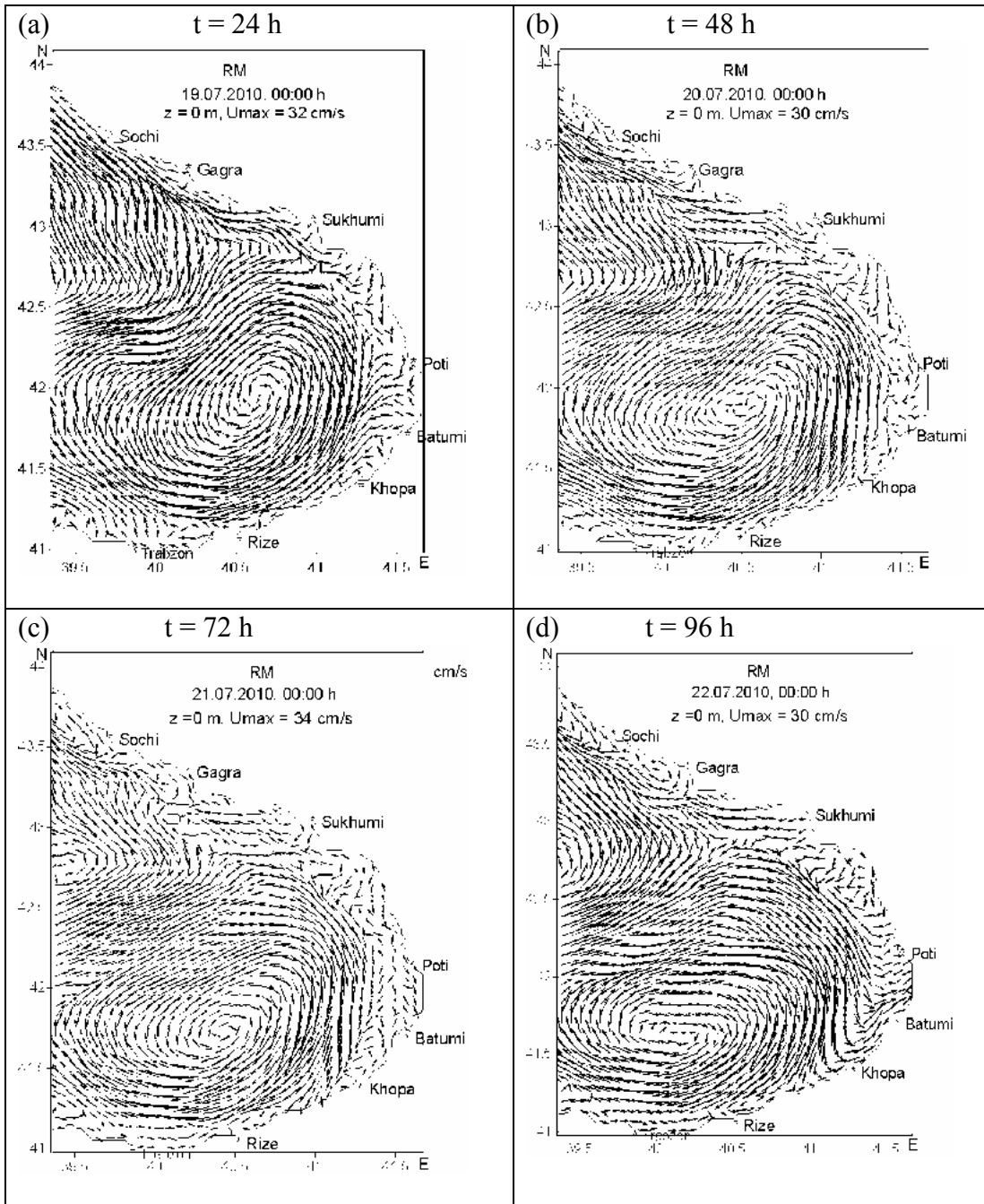
Fig.5. The surface current fields predicted by RM-IG at (a) 24 h, (b) 48 h, (c) 72 h, (d) 96 h.

Figs. 5-7 illustrate prognostic fields of current, temperature and salinity received by the RM-IG at the time moments 24, 48, 72 and 96 h after beginning of integration (18.07.2010, 00:00 h). Circulation patterns are shown on z = 0, but temperature and salinity fields – on z = 20 m.

From Fig.5 is obvious that Batumi anticyclonic eddy insignificantly depends on changeability of atmospheric wind forcing (see, Fig.1) and is rather stable formation; it is observed during all forecasting period without strong changes. The Batumy eddy most of all is exposed to some changes for the both third and fourth days of the forecast and its centre is displaced a little on the West side (Fig.5d). Here the narrow zone with width about 20-25 km along seashore is obviously allocated, where movement of waters sharply differs from other part of the regional area and currents have tendency to vortex formation of very small sizes.
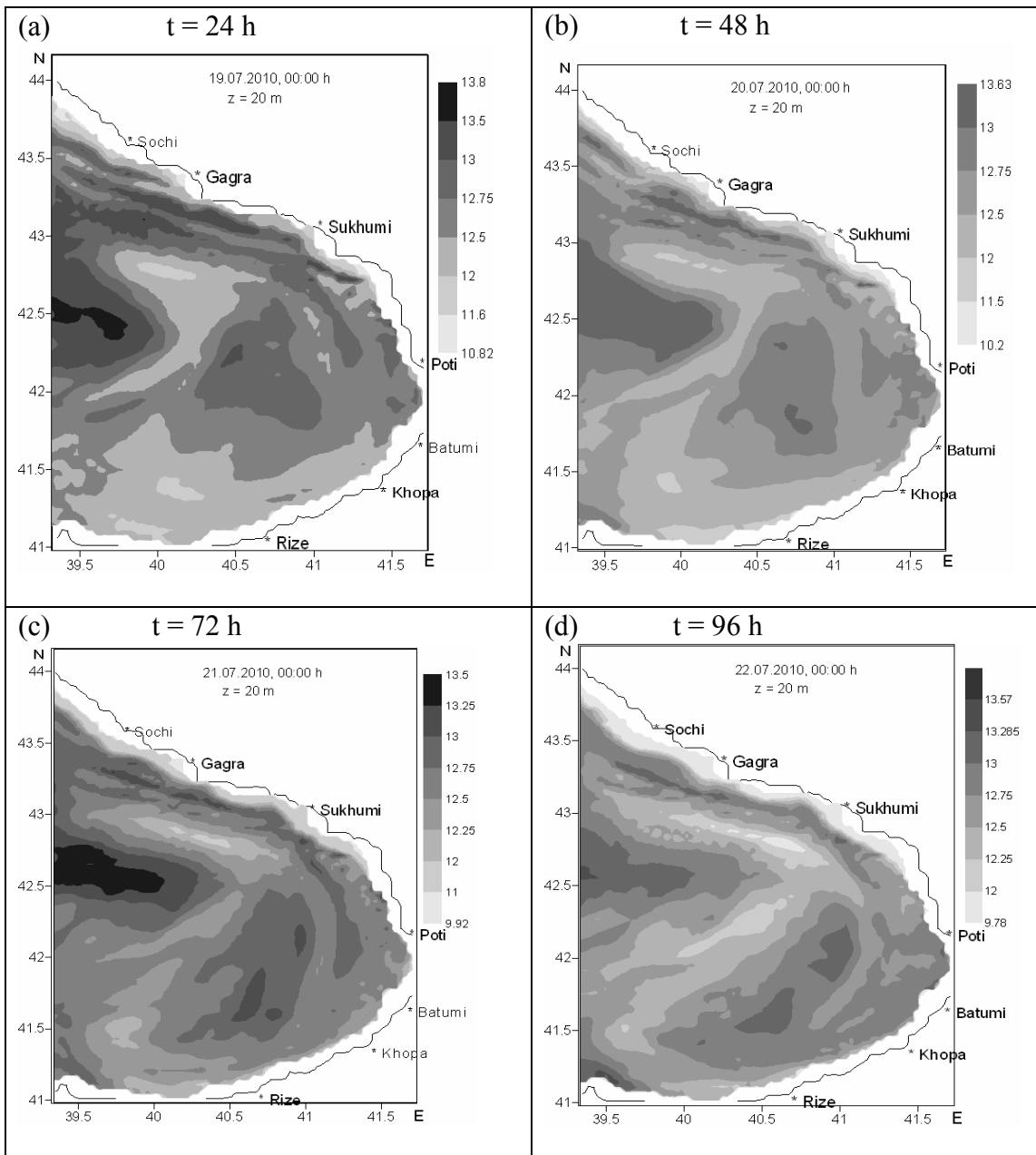
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Fig.6. The temperature fields on depth of 20 m predicted by RM-IG at (a) 24 h, (b) 48 h, (c) 72 h, (d) 96 h.

From Figs. 6 and 7 are shown that prognostic temperature and salinity fields are changing a little during the forecasting period, but main features of distribution of these fields remain same.

Figs. 8-10 illustrate prognostic fields of current, temperature and salinity computed by BSM of MHI. The patterns are on the same horizons and at the same time moments as in Figs. 5-7.

Comparison of Fig. 8 with Fig. 5 shows that results of forecast of Batumi eddy from both RM-IG and BSM are closed (configuration, sizes, intensification). The most considerable distinctions are observed in the narrow zone along the coastal line. The basic distinctions between temperature fields predicted by the RM-ig and the BSM is reduced to that in a zone of development Batumi eddy values of temperature predicted by the RM-ig are higher than values of temperature predicted by the BSM (see, Figs 6 and 9).

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Concerning salinity fields, there are more similarity between fields predicted from both RM-IG and BSM. Particularly, in both cases the zones of lower salinity are in the central area of Batumi anticyclonic eddy.
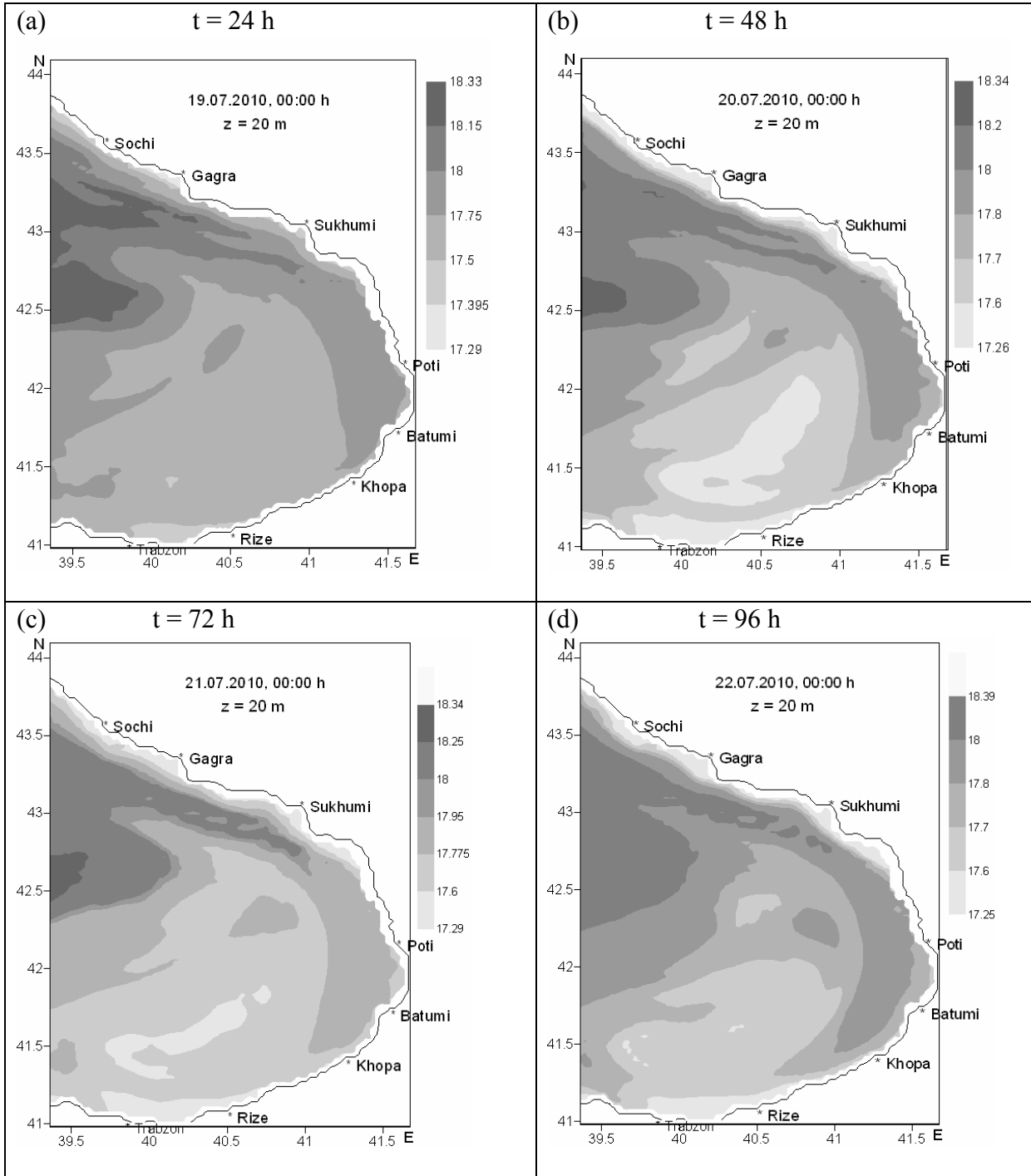

Fig.7. The salinity fields on depth of 20 m predicted by the RM-IG at (a) 24 h, (b) 48 h, (c) 72 h, (d) 96 h.
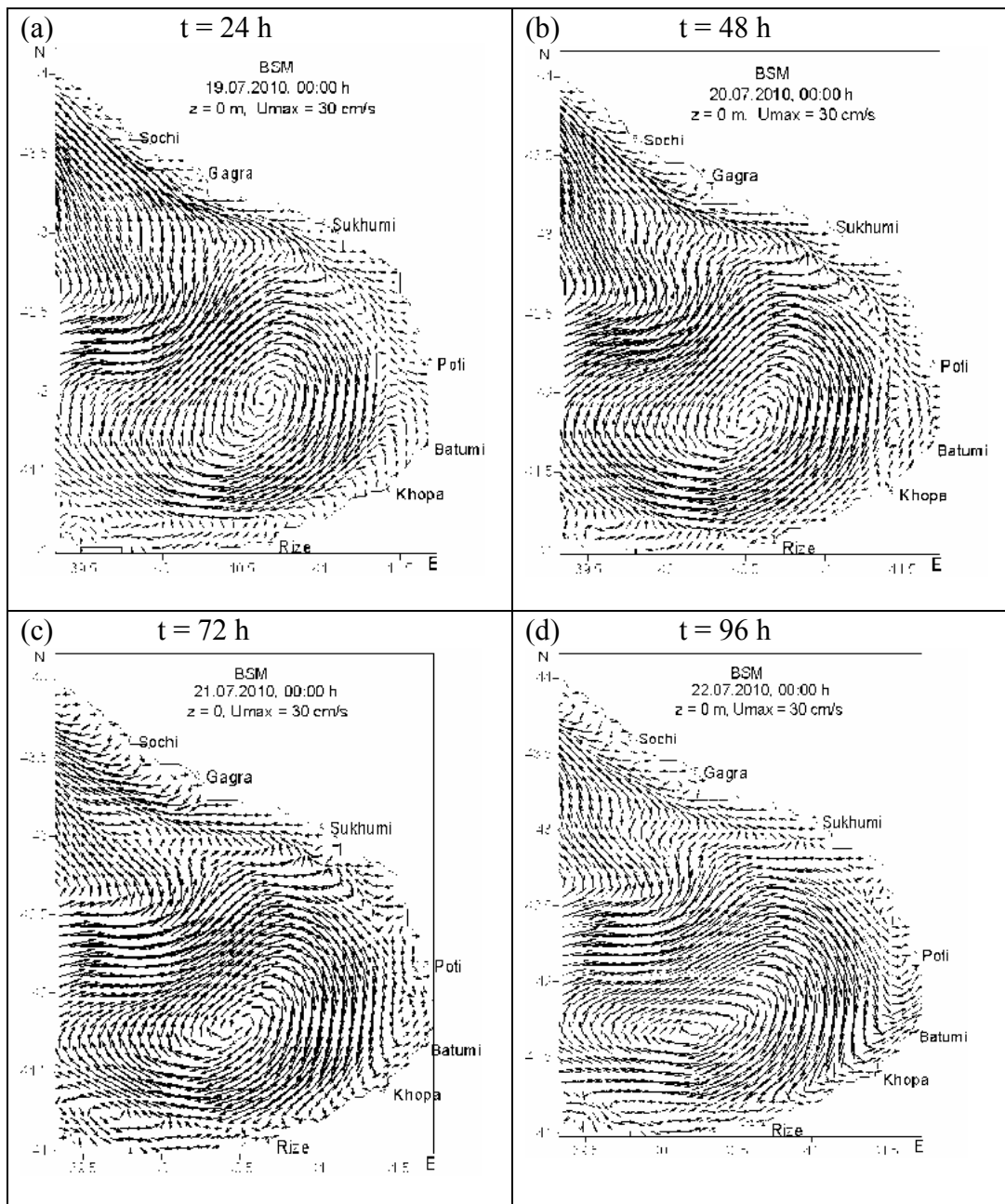
Fig.8. The surface current fields predicted by the BSM of MHI at (a) 24 h, (b) 48 h, (c) 72 h, (d) 96 h.
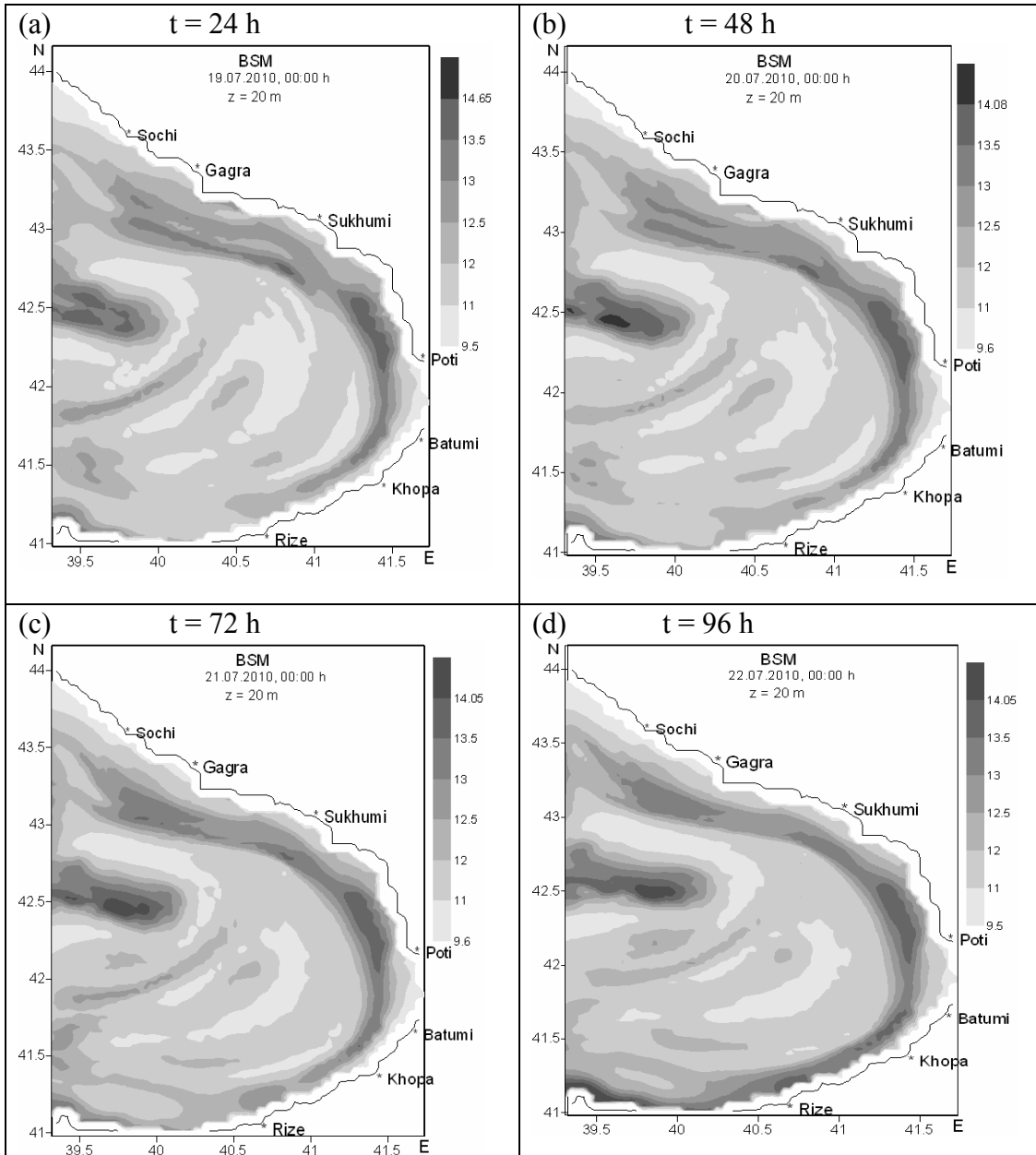
Fig.9. The temperature fields on depth of 20 m predicted by BSM of MHI at (a) 24 h, (b) 48 h, (c) 72 h, (d) 96 h.
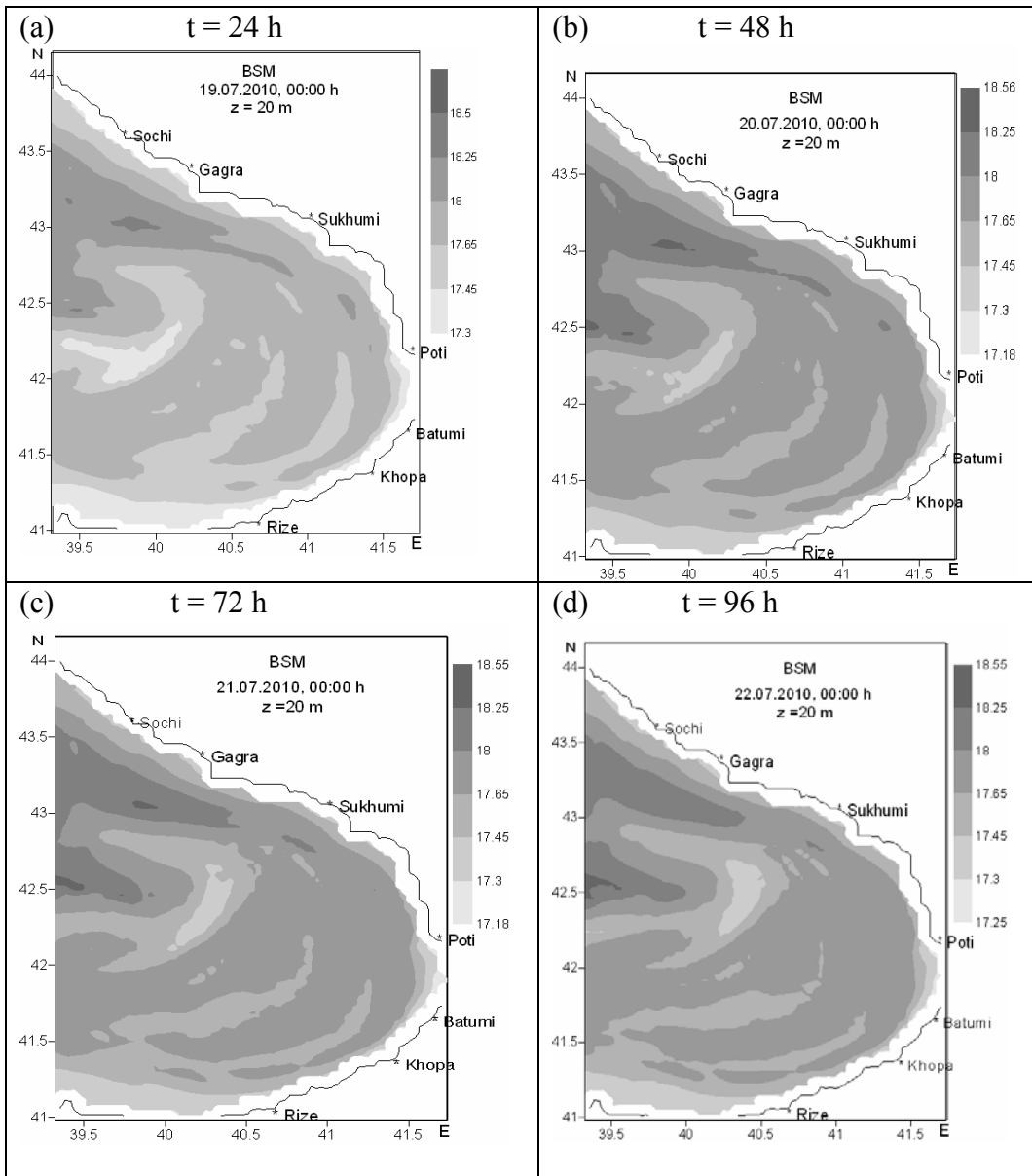
Fig.10. The salinity fields on depth of 20m predicted by BSM of MHI at (a) 24 h,
(b) 48 h, (c) 72 h, (d) 96 h.

4. Summary

A regional forecasting system allowed to predict flow, temperature and salinity fields with 1 km spacing in the easternmost part of the Black Sea is developed. A core of the forecasting system is the hydrostatic baroclinic regional model of the Black Sea dynamics, which is nested in the BSM of MHI. Main features of regional circulation for July 18.07 – 22.07, 2010 predicted both by the BM-IG and BSM of MHI are practically the same, but more differences are observed in the narrow zone along shoreline. In this near-shore zone the flow predicted by RM is characterized by more tendency to form eddies of small sizes. Some differences are also observed in temperature and salinity fields predicted by both model.

Finally, it should be noted that at present to verify results of the forecast by comparison with the real data is not possible because of the absence of the observational data. However, such comparisons have been done during pilot experiment within the project ARENA in 2005, which showed an ability of the regional model to predict hydrophysical fields with sufficient accuracy [19].

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Некоторые результаты прогноза гидродинамических процессов в восточной части Чёрного моря

Автандил А. Кордзадзе, Демури И. Деметрашвили

Резюме

В рамках международных научно-технических проектов Евросоюза *ARENA* и *ECOOP* разработана региональная прогностическая система для предсказания трёхмерных полей течений, температуры и солёности в самой восточной части Чёрного моря. Прогностическая область ограничена Кавказской и Турецкой береговыми линиями и западной жидкой границей, совпадающей с 39.36^0 в. д. Основным ядром прогностической системы является трёхмерная региональная прогностическая модель динамики Чёрного моря с высоким разрешением, разработанная в Институте геофизики им. М. Нодиа. Региональная модель с пространственным шагом, равным 1 км, вставлена в модели динамики всего Чёрного моря Морского гидрофизического Института (МГИ, Севастополь/Украина) с пространственным шагом, равным 5 км. Все входные данные, необходимые для расчёта 4 дневных прогнозов, получаются регулярно из МГИ через Интернет. В настоящее время система готова для оперативного функционирования.

ჰიდროდინამიკური პროცესების პროგნოზის ზოგიერთი შედეგი შავი ზღვის აღმოსავლეთ ნაწილში

ავთანდილ ა. კორძაძე, დემური ი. დემეტრაშვილი

რეზიუმე

ევროკავშირის საერთაშორისო სამეცნიერო-ტექნიკური პროექტების *ARENA* და *ECOOP* ფარგლებში შემუშავებულია რეგიონალური პროგნოზის სისტემა დინების, ტემპერატურისა და მარილიანობის სამგანზომილებიანი ველების წინასწარმეტყველების მიზნით შავი ზღვის უკიდურესი აღმოსავლეთ ნაწილისათვის. რეგიონალური არე შემოსაზღვრულია კავკასიისა და თურქეთის სანაპირო ხაზებითა და დასავლეთის თხევადი საზღვრით, რომელიც ემთხვევა 39.36^0ა. გ.-ს. პროგნოზის სისტემის ძირითად ბირთვს წარმოადგენს მაღალი გარჩევისუნარიანობის მქონე შავი ზღვის დინამიკის სამგანზომილებიანი რეგიონალური პროგნოსტიკული მოდელი, რომელიც შემუშავებულია მ. ნოდიას გეოფიზიკის ინსტიტუტში. რეგიონალური მოდელი 1 კმ სივრციითი ბიჯით ჩადგმულია ზღვის ჰიდროფიზიკის ინსტიტუტის (ზჰი, სევასტოპოლი/უკრაინა) მთლიანი შავი ზღვის დინამიკის მოდელში 5 კმ სივრციითი ბიჯით. 4 დღიანი პროგნოზის გათვლისათვის საჭირო ყველა შემავალი მონაცემი რეგულარულად მიიღება ინტერნეტის საშუალებით ზჰი-დან. ამჟამად, სისტემა მზადაა ოპერატიული ფუნქციონირებისათვის.