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# Dynamical processes developed in the easternmost part of the Black Sea in warm period for 2010-2013

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*Abstract*

*In the paper the prognostic hydrophysical fields in warm period for 2010-2013, calculated on the basis of the regional forecasting system of the Black Sea state for the easternmost part of the Black Sea, are analyzed. The analysis of these results shows that the regional circulating processes in the warm and cold periods are in the certain degree different. In the warm period the main element of the regional circulation is frequently the Batumi anticyclonic eddy which predetermines a specific hydrological mode in this part of the Black Sea, but except this eddy here strongly non-stationary processes of generation, evolution, and dissipation of cyclonic and anticyclonic vortexes of different sizes permanently develop.*

## 1. Introduction

In [1-5] the regional forecasting system of the dynamical state for the Black Sea easternmost part was described, which is developed at M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University. The regional forecasting system provides 3 days' forecast of sea current, temperature and salinity with 1 km spacing for this water area (the regional area of forecasting is separated from the open part by the western liquid boundary coinciding approximately with the meridian 39.08° E). As a result of functioning of the forecasting system the database with significant volume of prognostic hydrophysical fields is created, which by high spatial - temporary detailing reflects development of dynamic processes in the Georgian sector of the Black Sea and its adjacent water area for 2010-2013. In [6-8] the some features of regional circulating processes are investigated on the basis of the analysis of this database. The analysis of calculated prognostic fields for 2010-2013 allows to reveal the basic features of variability of dynamic processes in the easternmost water area of the Black Sea. General regularity is that during the entire year in the considered sea water area the non-stationary processes develop, where there is a continuous generation, evolution and disappearance of cyclonic and anticyclonic eddies of different sizes, but the circulating structure in the sea upper layer is different in warm (April - October) and cold (November - March) seasons of the year.

The main goal of the paper is to investigate in more detail dynamical processes developed in the easternmost part of the Black Sea during the warm period for 2010-2013 on the basis of the analysis of forecasted hydrophysical fields. Thus, this paper may be consider as continuation of the researches started in [6-8].

## 2. Results and Discussion

The regional model of Black Sea dynamics, which is the core of the regional forecasting system [1-5], uses a grid having 215 x 347 points on horizons with 1 km spacing. On the vertical the non-uniform grid with 30 calculated levels on depths: 2, 4, 6, 8, 12, 16, 26, 36, 56, 86, 136, 206, 306,…, 2006 m are considered. The time step is equal to 0.5 h.

The analysis of results of calculated forecasted fields for 2010-2013 shows, that in the early spring begins to be formed the specific structure of the surface regional circulation, which

considerably differs from circulation of the cold period. The main component of the regional circulation in the warm season is frequently the Batumi anticyclonic eddy which usually arises in March or April and in the most cases persists during the all warm season. It disappears in process of approach of a cold season in October, but sometimes in the second half of November. The Batumi eddy is one of the quasi-stable anticyclonic eddies generated on the coastal side of the Rim current and is characterized by more stability and intensity among the coastal eddies in the Black Sea [9, 10]. There are also other cyclonic and anticyclonic eddies of different sizes generated and evaluated in the easternmost part of the Black Sea.

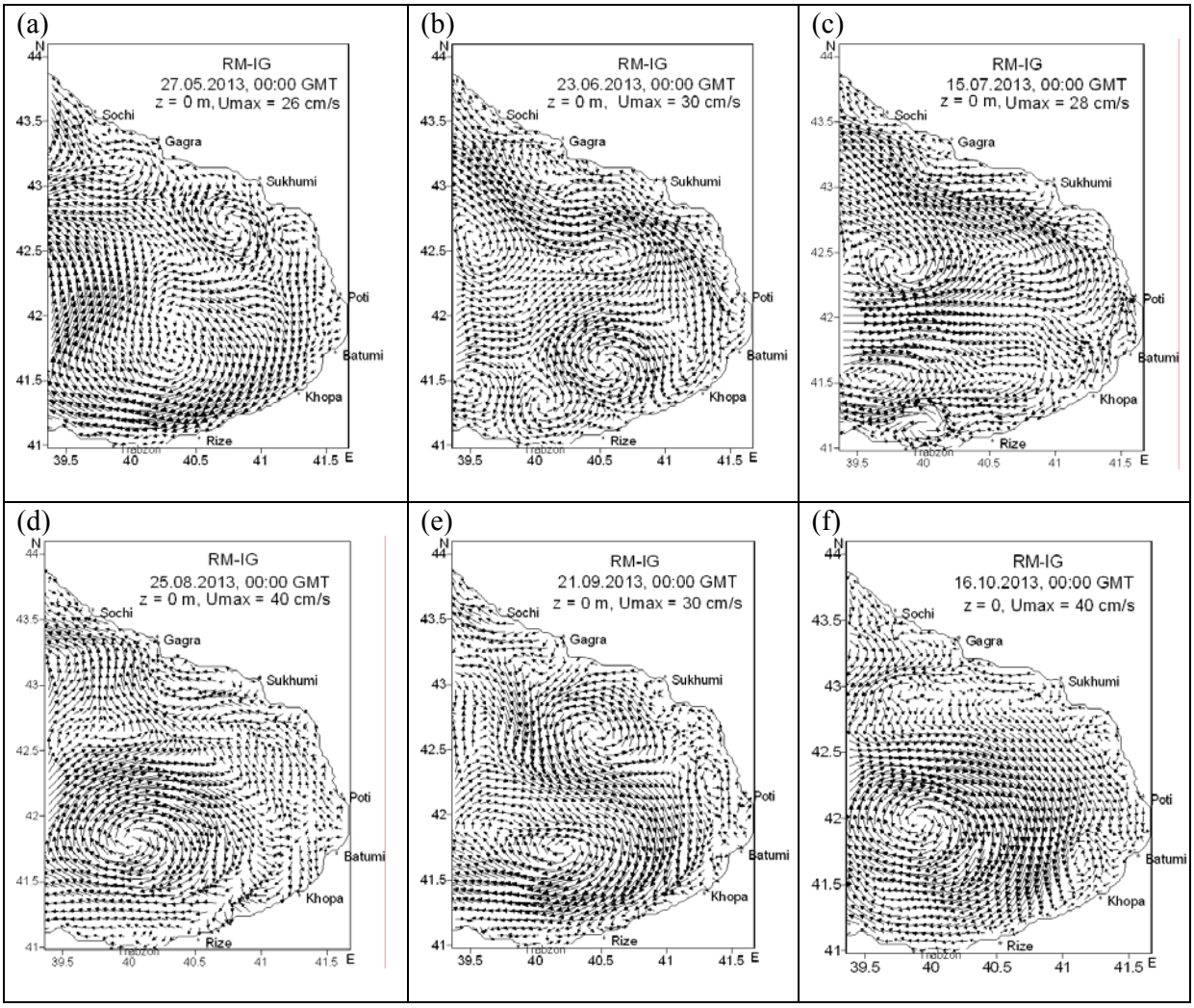


Fig.1. The evolution of the surface regional circulation in the easternmost part of the Black Sea in
2013: (a) – May 27, (b) – June 23, (c) – July 15, (d) – August 25, (e) – September 21,
(f) – October 16.

Figs. 1-4 evidently illustrate the evolution of the regional surface circulation in the warm season for 2010-2013 in the easternmost part of the Black Sea. In 2013 the Batumi eddy began to be formed practically in March in the south part of the considered easternmost water area and in April was a little bit increased in the sizes up to a diameter 60-80 km. It should be noted that the generation of the anticyclonic eddy in this area was also observed in the winter season, but it has not received the further development and has disappeared. Fig.1 illustrates further evolution of the regional circulation in May, and summer and autumn months. Except for the Batumi eddy, in May

in water area near the city of Sukhumi there is observed formation of the small anticyclonic eddy (Fig.1a). Formation of such eddy near Sukhumi is also noted in [9]. Besides, there are also very small nearshore unstable eddies near Gagra and in the south water area from Sukhumi. We have to note that along the

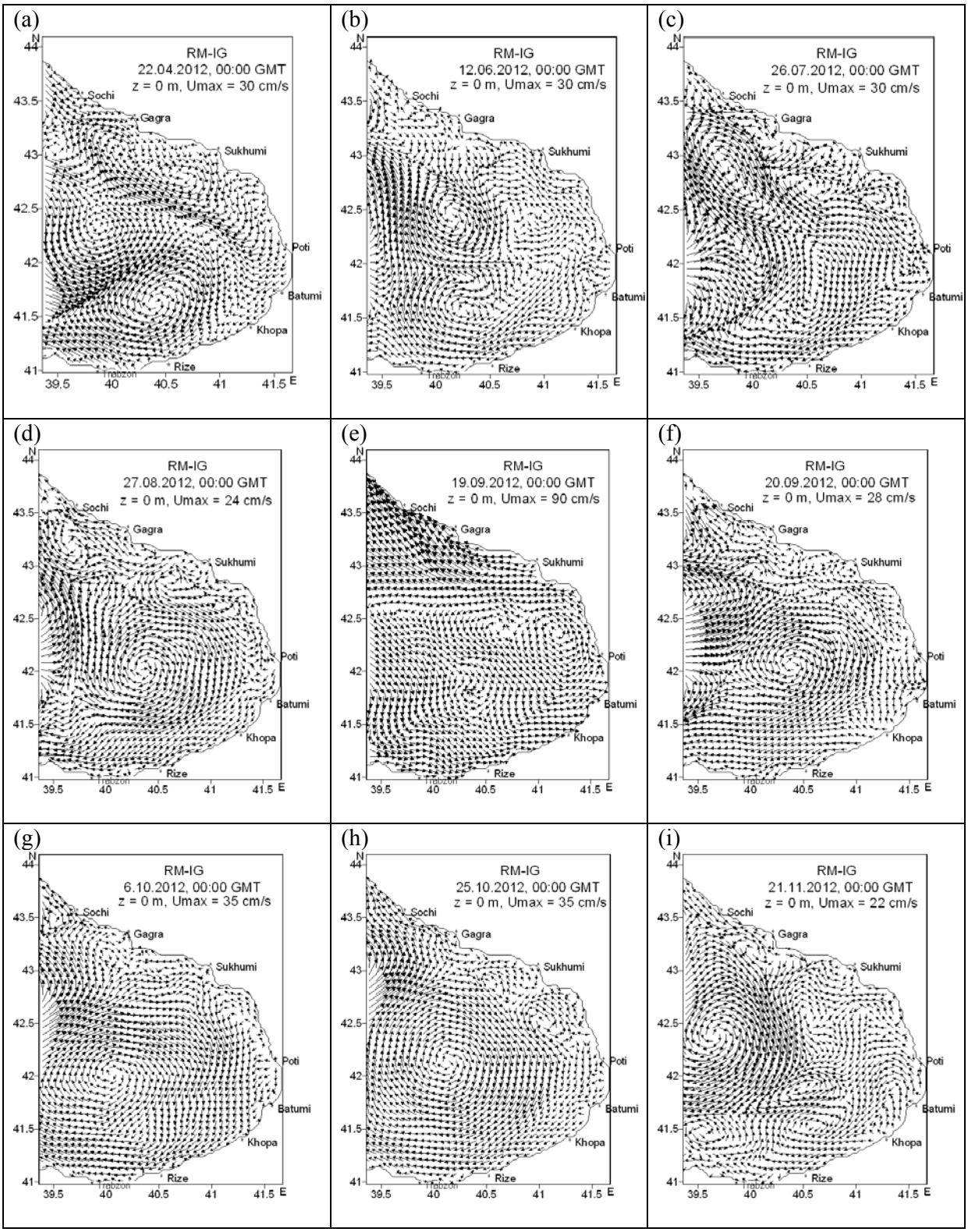


Fig.2. The evolution of the surface regional circulation in the easternmost part of the Black Sea in

2012: (a) - April 22, (b) – June 12, (c) – July 26, (d) – August 27, (e) – September 19, (f)- September
20, (g)- October 6, (h) – October 25, (i) – November 21.

Caucasus shoreline the formation of the narrow zone is very often observed, where generation of small unstable eddied are taking place. About such phenomenon was noted in [3, 6-8]. The Batumi eddy in June 2013 was less intensive then in May 2013, but in June the formation of other cyclonic and anticyclonic eddies was observed (Fig. 1b). These eddies were with diameter about 25-40 km and were exposed to fast changes.

The structure of 2013 summer circulation appreciably differed from circulation structure of the previous years by that the Batumi anticyclonic eddy in July circulation was practically absent (Fig. 1c). Since August the Batumi eddy arose again (Fig.1d) and became more intensive in September and October (Fig. 1e and 1f). In circulating pictures the formation of small coastal vortical formations along the Caucasian coast is well visible as well**.** For example, there are well visible the cyclonic eddies near the city of Poti (Fig.1e), between Sukhumi and Poti (Fig.1f), near Khopa (Fig.1f). These small coastal eddies have time of few days' existence and quickly disintegrate. It should be noted that the formation of analogical small eddies with a diameter of 2-8 km were observed in the Gelendzhik region in the autumns seasons of 2007-2008 using methods of hydrophysical investigations [11]. The Black Sea circulation in the easternmost water area in the warm season for 2013 differed with that the disintegration of the Batumi eddy in this year began in the late autumn. The weakening of intensity of the Batumi eddy and transformation of circulation to a new mode characteristic for the cold period was not observed up to the end of November.

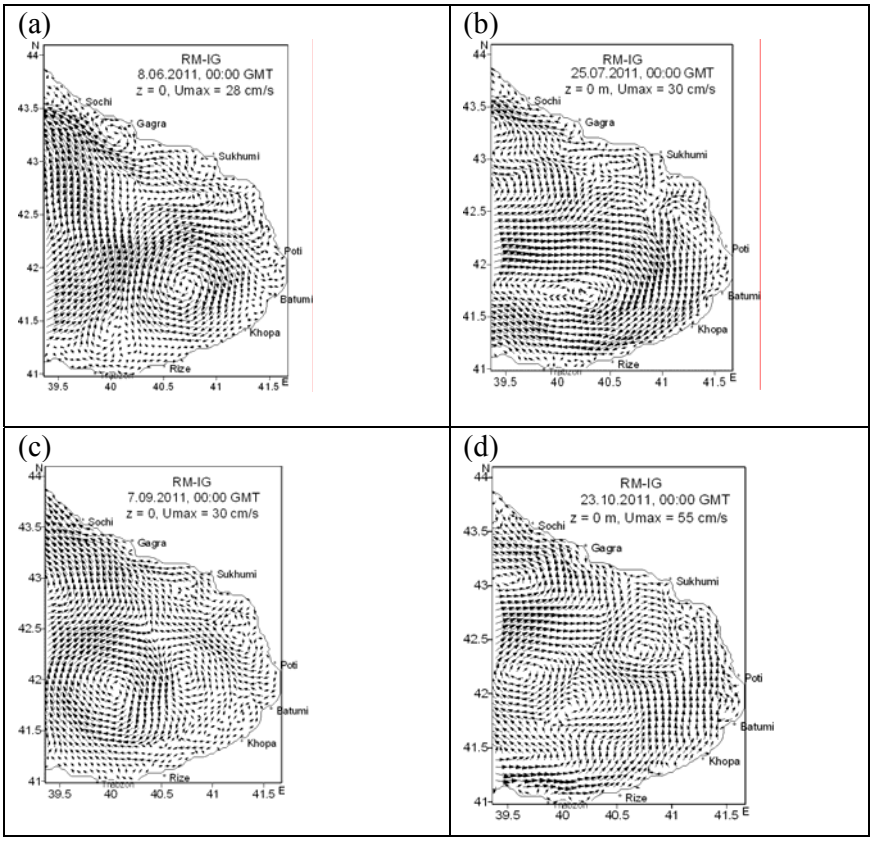


Fig.3. The evolution of the surface regional circulation in the easternmost part of the Black Sea in 2011: (a) - June 8, (b) - July 25, (c) – September 7, (d) – October 23.

In 2012 the common features of the regional circulation during the warm season (Fig. 2) were similar to 2013 warm season regional circulation (Fig.1), but differed by some specific

features. The generation of the Batumi eddy was observed by the end of March in the southwestern part of the considered area. In April this anticyclonic eddy grew in the sizes and was present throughout the month. From Fig.2a is well visible very interesting circulating structure formed on 00:00 GMT, 22 April 2012: there is formed specific vortex structure, which has a form of the dipole consisting from cyclonic and anticyclonic eddies. These eddies plays a role of obstacle, between of which the current is passing through narrow strip. Therefore, here a zone of the current intensification with speed about 30 cm/s is observed. Analogical phenomenon is observed in the second narrow zone between one of the components of the dipole – cyclonic eddy and relatively small anticyclonic eddy formed near Sukhumi, were the high speeds of the current are observed too. In the middle of May, the anticyclonic eddy amplified and by the end of the month weakened. At the beginning of summer 2012, the Batumi anticyclonic eddy was stretched along the meridian and as a result, in mid-June two anticyclonic eddies were formed (Fig.2b). At the beginning of July, the Batumi eddy was observed in the northwestern part of the considered easternmost water area and by the end of July this vortex extended

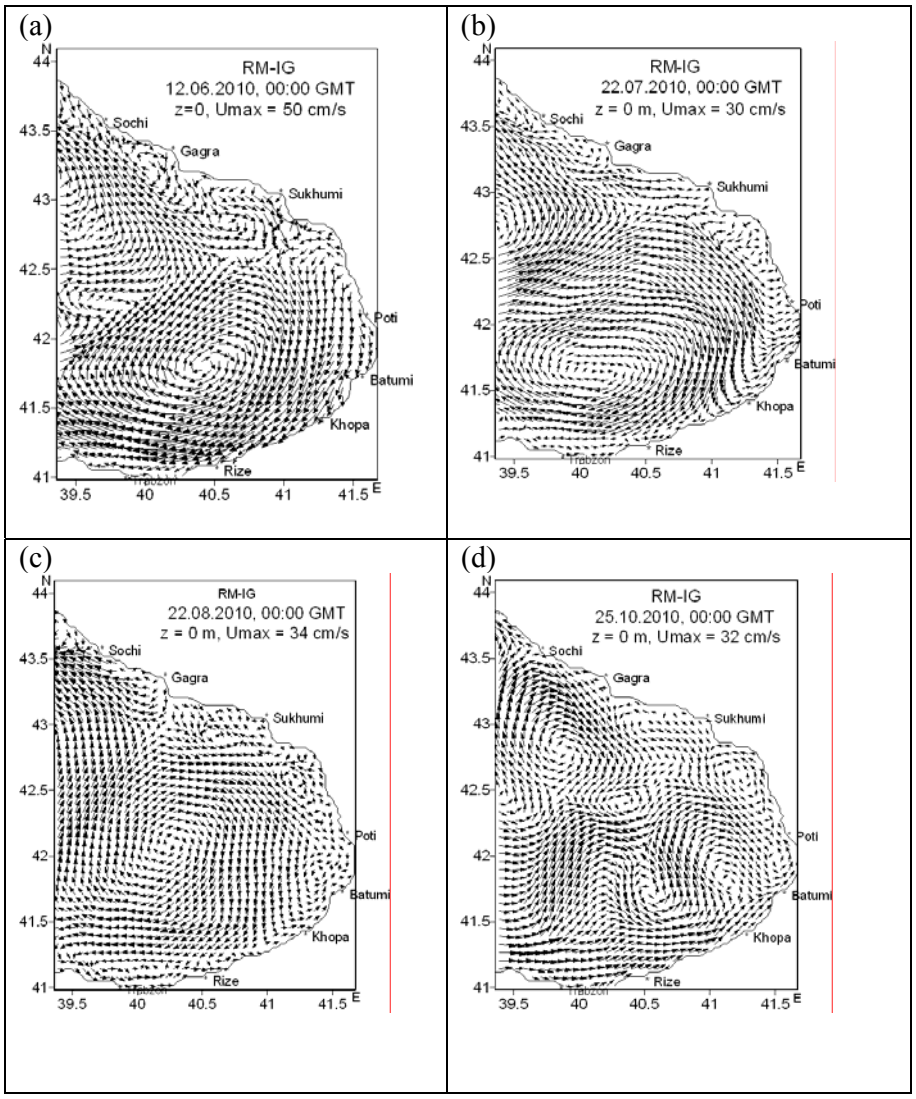


Fig.4. The evolution of the surface regional circulation in the easternmost part of the Black Sea in 2010: (a) - June 12, (b) - July 22, (c) - August 22, (d) - October 25.

in a southern direction (Fig.2c). In August the Batumi eddy was observed in the central area with diameter about 100 km (Fig.2d). The arrangement and intensity of the Batumi eddy was practically kept during September except for some cases.

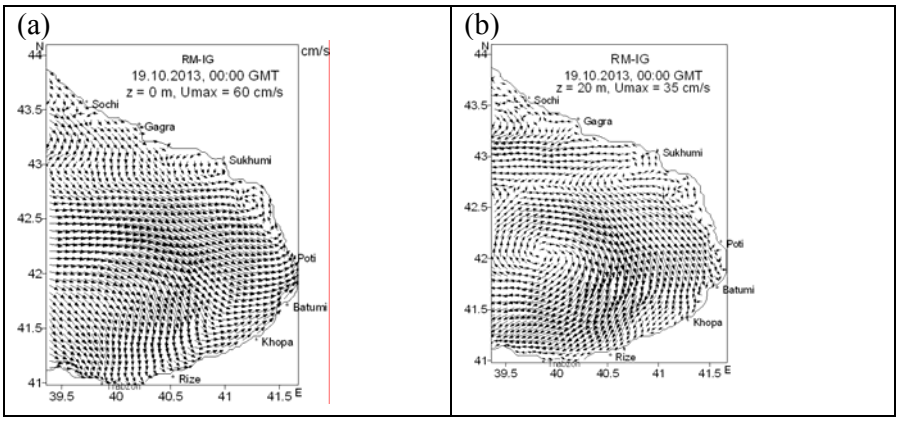


Fig.5. The surface circulation in the easternmost part of the Black Sea on 19 October 2013 on horizons (a) z = 0 m and (b) z = 20 m.

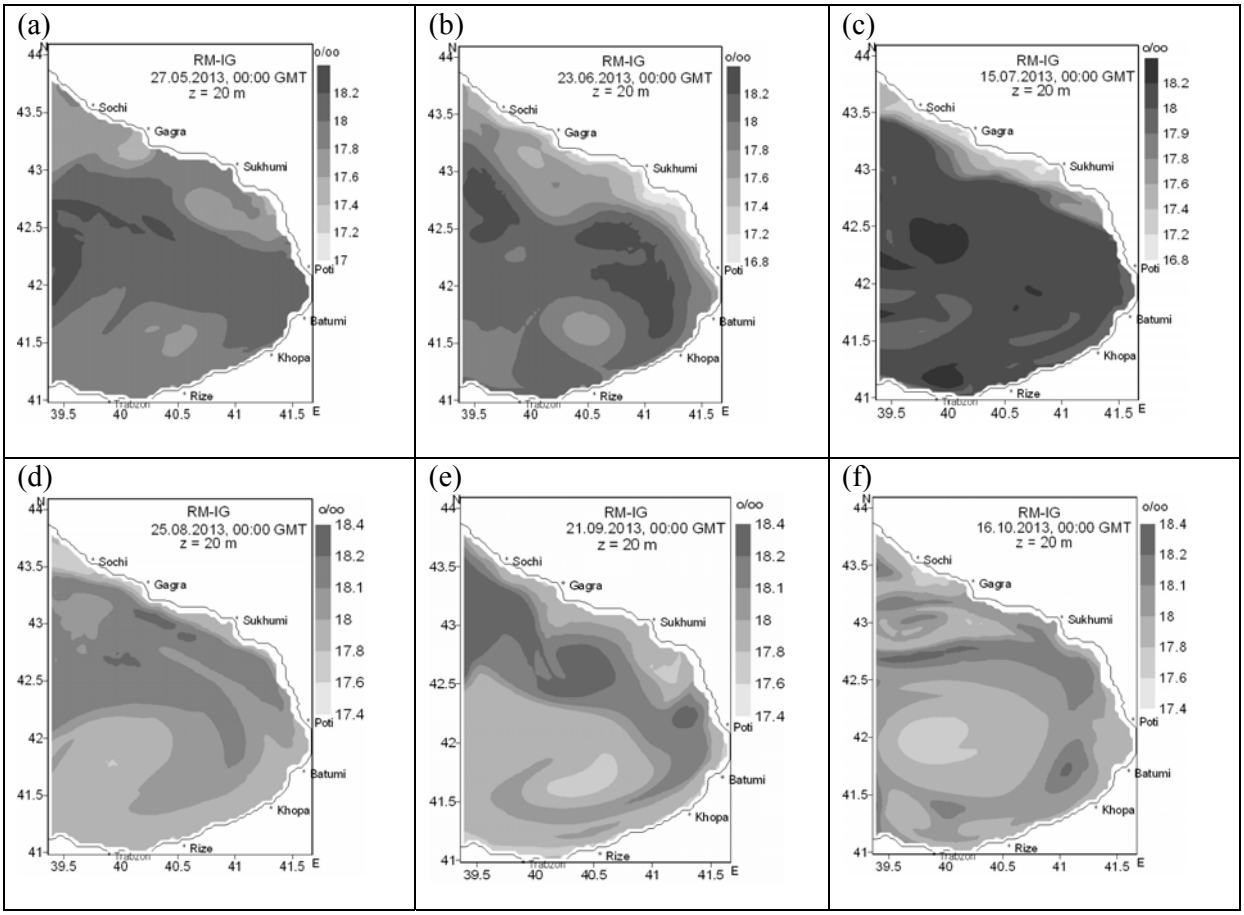


Fig. 6. The evolution of the salinity field on z = 20 m in the easternmost part of the Black Sea in 2013: (a) - May 27, (b) - June 23, (c) -July 15, (d) - August 25, (e) - September 21, (f) - October 16.

In Figs. 2e and 2f are shown circulation patterns in two next days - on 19 and 20 September 2012, when the surface circulating structures were significantly different in these days. On 19

September the Batumi eddy practically did not exist, but the next day it was well advanced. It is possible to explain these phenomenon by sharp change of meteorological conditions above the Black Sea during this short time interval. Strong winds developed on 19 September 2012 (Fig.2e) provided disappearance of the Batumi eddy and strengthening of the sea current speed up to 60 cm/s. After the atmospheric wind became less intensive the eddy was restored for the short period of time (Fig.2f). In October the Batumi eddy became more intensive and has covered almost all easternmost areas (Fig.2g and 2h) except for a narrow zone of small vortex formations along the Caucasus sealine. This zone plays a role of the interfering factor for the right peripheral current of the Batumi eddy to reach the Georgian coast. The Batumi eddy existed in November 2012 too, but in the sizes it decreased and its centre moved to north – west (Fig. 2i). From Fig.2i is well visible that except for this eddy, in the considered part of the sea basin other cyclonic and anticyclonic eddies of the rather smaller sizes are also formed. By the end of November 2012 the gradual disintegration of this eddy was observed and circulation was transformed to circulation of the cold period.

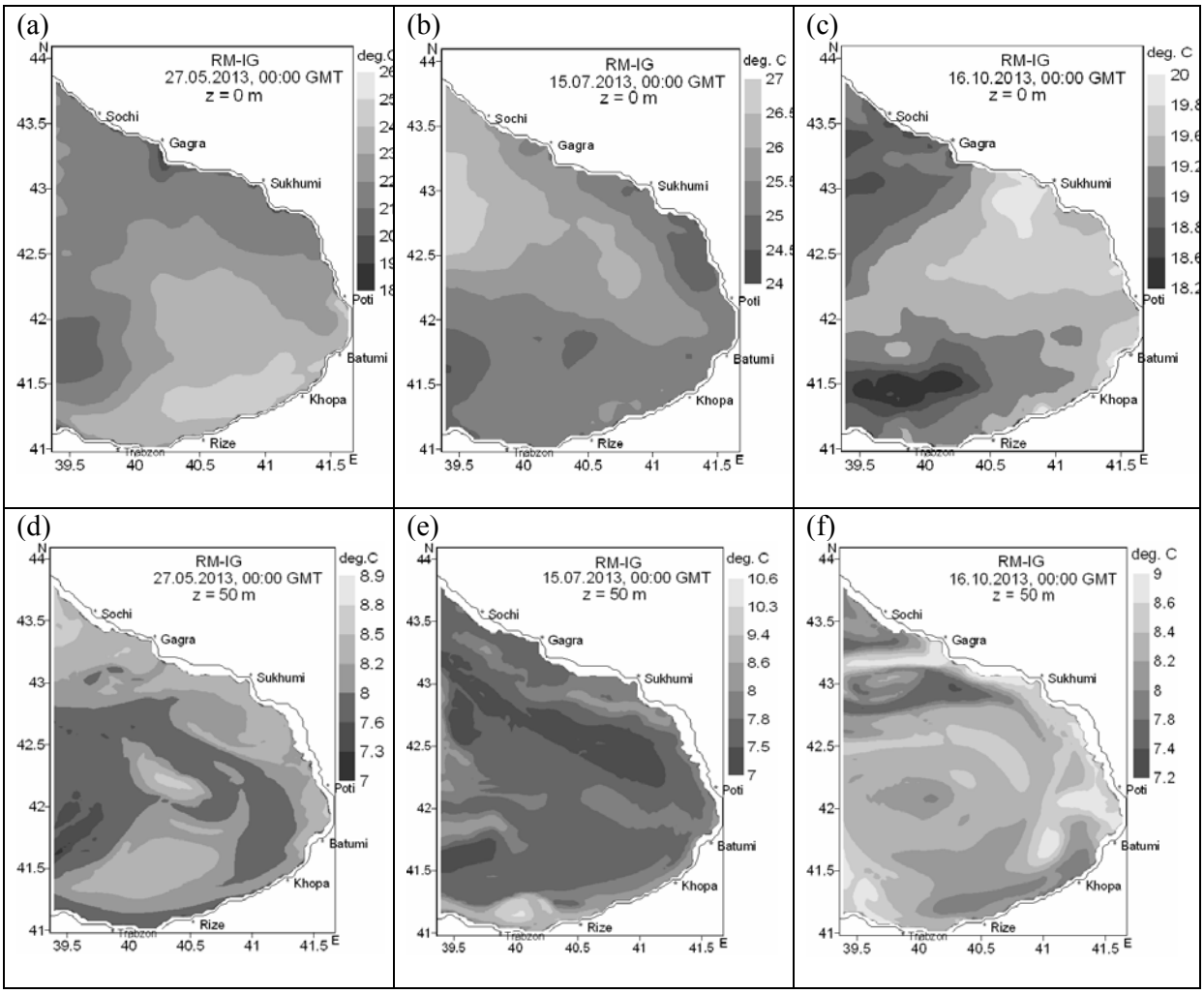


Fig. 7. The evolution of the temperature field in the easternmost part of the Black Sea in 2013: (a) - z = 0, May 27; (b) - z = 0, July 15; (c) - z = 0, October 16; (d) - z = 50 m, May 27; (e) - z = 50 m, July 15; (f) - z = 50 m,October 16.

Fig.3 Illustrates the evolution of the regional circulation in the easternmost part of the Black Sea during June-October 2011. The summer circulation structure in 2011 was characterized relatively by more expressed anticyclonic eddy. This eddy began disintegration at the beginning of

October and as a result in this month the regional circulation was already transformed into the current with small vortexes and the circulating mode already had structure characteristic for a cold season (Fig.3e).

Unlike summer circulation for 2011-2013 summer circulation in 2010 was characterized by sharply distinguished features [7]. The main feature was that the Batumi eddy was the steadiest and most intensive vortical formation during all summer period (Fig.4). It achieved maximal intensity in August and covered the significant part of the considered regional area. In the October the disintegration of the Batumi eddy was observed. The warm season of 2010 was especial not only from the point of view of the regional circulating characteristics of the easternmost part of the Black Sea, but also abnormal meteorological conditions. The summer 2010 was very hot last decades not only in Georgia, also on the territory of Europe. In [7 ] the opinion was stated that the anomalous temperature regime obviously influenced the mode of evaporation and precipitation, and, eventually, the thermohaline conditions were favorable for the formation of an intense anticyclonic vortex. The opinion on a paramount role of atmospheric thermohaline forcing on formation and evolutions of the Batumi anticyclonic eddy becomes more argued by numerical researches carried out in [12], which have shown significant sensitivity of the Batumi eddy generation to variable thermohaline conditions.

Strong winds over the Black Sea can disappear the Batumi eddy only in the sea uppermost layer, but in lower layers it is kept practically without change. This fact illustrates Fig.5, where circulation patters corresponding to 00:00 GMT, 19 October 2013 are shown on the sea surface and on the horizon z = 20 m. During 19 October the strong winds operated over the Eastern Black Sea. From Fig.5 is well visible that strong winds provided the disappearance of the Batumi eddy on z = 0 m and amplification of the surface current speed up to 60 cm/s, but on z = 20 m the Batumi eddy was kept practically without change. The maximal current speeds have decreased within upper 20 m layer from 60 cm/s up to 35 cm/s. Our previous investigations showed that when the Batumi eddy is very intensive formation it covers deep layers approximately up to 300 м, below which there is a disintegration of this eddy into smaller vortical formations [6-7].

With the purpose of illustrating annual evolution of the salinity field in Fig. 6 the evolution of the salinity field from May to October 2013 on z = 20 m is shown. The time moments, when the calculated salinity fields are shown in this Figure, are the same as in Fig.1. Comparison of Figs.1 and 6 shows good correlation between salinity and flow fields. There is obvious that generally, to the central area of cyclonic eddies corresponds waters with high salinity and to the central areas of anticyclonic eddies – the waters with low salinity. This fact is well known [13] and it is easy to explain by features of circulation processes. In particular, the upward flows in the center of the cyclonic eddy promote more salty waters being carried from deep layers in the upper layers and the downward flows in the central part of the anticyclones eddy transfer less salty waters from the upper layers downwards.

The temperature field is exposed to significant quantitative and qualitative changes during the warm season. This fact is illustrated by Fig.7, when the temperature fields are shown on z = 0 and z = 50 m. the character of change of the surface temperature is basically determined by heat exchange between the sea and atmosphere. on the horizon z = 50 m formation of the cold intermediate layer is evidently observed, which is well expressed in summer season end covers significant part of the considered area.

## 3. Conclusion

Researches carried out on the basis of the analyses of the database of hydrophysical fields created as a result of functioning of the Black Sea regional forecasting system led to increase our present level of knowledge about variability of the Black Sea circulation in its easternmost water area. Our investigations based on the database 2010-2013 showed that the regional circulation structure for the warm period from March to October is characterized by features distinctive from the cold period. The main element of the regional circulation for this period is frequently, the

Batumi anticyclonic eddy, the intensity and extent of which varieties during this period. The weakening and disappearance of this eddy occurred in September or October in 2010 and 2011, but in 2012 and 2013 it continued existing even in November. Apparently among the external factors the atmospheric thermohaline forcing has a prime role in formation and evolution of the Batumi eddy, but the strong winds developed over the Black Sea easternmost area, which render smoothing action on sea circulation, can reduce intensity of the Batumi eddy or temporarily disappear it. The Batumi eddy is observed up to depths approximately 300-400 kms, and in more deep layers the gradual transformation of the circulation structure and formation of more small eddies takes place. Most intensive and steady the Batumi eddy was in summer 2010, when was abnormal hot for last decades. In that case when the Batumi eddy is intensive and occupies a significant part of the easternmost water area, it forms the certain mode of salinity: salinity of waters considerably decreases in the central part of the vortex and the peripheral current of the Batumi eddy promotes penetration of more salty waters from the open part of the Black Sea in the easternmost part.

Our investigations show also that the anticyclonic formations similar to the Batumi eddy can also occur in winter season in the easternmost part of the Black Sea, but they are less steady and can not exist for the long period as in warm period.

Except for the Batumi eddy, there is continuously generation, deformation and disappearance of the cyclonic and anticyclonic vortex formations of difference sizes in the easternmost water area. Among such eddies are the small nearshore eddies which are frequently formed in the narrow zone along the Georgian shoreline.

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## Динамические процессы, развивающиеся в восточной части Черного моря в теплый период 2010-2013 гг.

Автандил А. Кордзадзе, Демури И. Деметрашвили, Александр А. Сурмава

Резюме

В статье анализируются прогностические гидрофизические поля, рассчитанные на основе региональной ситемы прогноза состояния Черного моря для крайне восточной части морского бассейна и соответствующие теплому периоду 2010-2013 гг. Анализ этих результатов показывает, что региональные циркуляционные процессы в теплый и холодный периоды года в значительной степени различны. В теплый период главным элементом региональной циркуляции часто является Батумский антициклонический вихрь, который предопределяет специфический гидрологический режим в этой части Черного моря, но кроме этого вихря здесь постоянно развиваются сильно нестационарные процессы генерации, эволюции и диссипации циклонических и антициклонических вихрей различных масштабов.

## შავი ზღვის აღმოსავლეთ ნაწილში განვითარებული დინამიკური პროცესები 2010-2013 წწ. თბილ სეზონში

ავთანდილ კორძაძე, დემური დემეტრაშვილი, ალექსანდრე სურმავა

სტატიაში გაანალიზებულია 2010-2013 წწ. თბილი პერიოდის შესაბამისი პროგნოზული ჰიდროფიზიკური ველები, რომლებიც გამოთვლილია შავი ზღვის მდგომარეობის პროგნოზის რეგიონული სისტემის საფუძველზე ზღვის უკიდურესი აღმოსავლეთ ნაწილისათვის. ამ შედეგების ანალიზი გვიჩვენებს, რომ რეგიონული ცირკულაციური პროცესები წლის ცივ და თბილ პერიოდებში მნიშვნელოვნად განსხვავდებიან. წლის თბილ პერიოდში ხშირ შემთხვევაში რეგიონული ცირკულაციის ძირითადი ელემენტია ბათუმის ანტიციკლონური გრიგალი, რომელიც განსაზღვრავს სპეციფიკურ ჰიდროლოგიურ რეჟიმს შავი ზღვის ამ ნაწილში, მაგრამ გარდა ამ გრიგალისა აქ მუდმივად ვითარდება სხვადასხვა მასშტაბის ციკლონური და ანტიციკლონური გრიგალების გენერაციის, ევოლუციისა და დისიპაციის ძლიერი არასტაციონარული პროცესები.