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SEASONAL VARIATIONS OF THE MESOSCALE CIRCULATION IN THE EASTERN BLACK SEA BASIN

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Грета Георгиева, Елисавета Пенева. СЕЗОННИ ВАРИАЦИИ НА МЕЗО-МАЩАБНАТА ЦИРКУЛАЦИЯ В ИЗТОЧНИЯ БАСЕЙН НА ЧЕРНО МОРЕ

Комбинирани алтиметрични данни, обработени и дистрибутирани от Морските услуги на Програма Коперник, са анализирани с цел да разкрият сезонната изменчивост на Черноморската мезомащабна циркулация. Зимната и лятната циркулация са с подобни хоризонтални характеристики, но с обратен знак: циклонична аномалия на основното черноморско течение и Батумския вихър през зимата и антициклонична – през лятото. Преходът между тези две състояния е през април–май и октомври–ноември. Хофмюлеровата диаграма на аномалията на свободната повърхност показва разпространение на сезонния сигнал със скорост от порядъка на 1 cm/s.

Greta Georgieva, Elisaveta Peneva. SEASONAL VARIATIONS OF THE MESOSCALE CIRCULATION IN THE EASTERN BLACK SEA BASIN

The multi-mission altimeter data for Black Sea Level Anomaly, processed and distributed by Copernicus Marine Environment Monitoring Service, are analyzed in order to reveal the seasonal variability of the Black Sea mesoscale circulation. Winter and summer circulation show similar patterns with opposite sign: cyclonic anomaly of the Rim current and Batumi eddy in winter and anticyclonic – in summer. The transition between these two stages occurs in April-May and October-November. The Hovmoler diagram of the SLA shows evidence of seasonal signal propagation with approximate speed ~ 1 cm/s.

Keywords: mesoscale eddies, surface circulation, Black Sea
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1. INTRODUCTION

The Black Sea is an inland basin with a surface area of about 4.2×10^5 km^2 (zonal and meridional dimensions ~1000 km and ~400 km) and a maximum depth of 2210 m. It is almost completely surrounded by land but not totally isolated from the neighbouring seas and the world oceans. The Bosphorus Strait is the connection with the Marmara Sea (which is connected to the Aegean Sea through Dardanelles) in the southwest. In the north, the Black sea is connected to the shallow Sea of Azov through the Kerch Strait. The largest river discharges (about ~80% of the total river runoff in the sea) are in the north-western part [1], where is the major shelf region. The rest of the basin is much deeper.

The circulation of the Black Sea is characterized by a basin-wide cyclonic boundary gyre known as Rim Current, which is formed by several factors: the curl of the wind stress field and the fresh water discharges from rivers (buoyancy forces), bathymetry and thermohaline fluxes [2]. Within this current, two or more smaller cyclonic cells are formed as depicted in Fig. 1 [4]. They are usually referred as eastern and western gyres. The Rim current is quasi-geostrophic as it engages the surface and several hundred meters water column. In addition to the principal Rim Current, the Black Sea circulation system contains many mesoscale eddies (see Fig. 1), meanders and filaments spread over the basin. The Rim Current separates the cyclonically dominated inner zone from the anticyclonically dominated coastal area [2]. The Danube, Constanta, Kaliakra, Bosphorus, Sakarya, Sinop, Kizilirmak, Batumi, Sukhumi, Caucasus, Kerch, Crimea, Sevastopol eddies reside on the coastal side of the Rim Current zone. They are quasistationary and quasiperiodical structures. This means that they do not exist there for the whole time once they were formed, but more properly they are regions of most probable formation or existence of an anticyclonic circulation. Actually the individual eddies travel slowly along the Rim current.

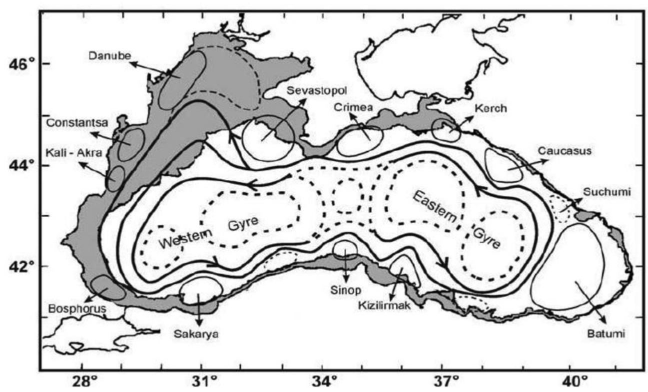

Fig. 1. Main features of the Black Sea circulation system [4]

In the Northwestern shelf region of the Black Sea the prevailing circulation is cyclonic with some anticyclonic gyres along the coast (the Danube eddy and the eddies in the vicinities of Odessa, gulf of Kalamita and the Karkinit bay). There is an exeption in cases of strong southern or southwestern winds; then the circulation transforms in anticylonic [3].

In addition to the above-mentioned there are three prominent points of bifurcation of the Rim current and some areas of convergence. The bifurcations are: (i) near the Bosphor Strait, (ii) southwestward of the Crimea peninsula, (iii) near the entrance to the Kerch-Tamanian shelf. The most significant location of convergence is in the vicinity of cape Kaliakra [3].

The upper layer circulation exhibits significant seasonal and interannual variability. The main driver is the atmospheric circulation variations. According to [3] there are two basic 2D patterns of the atmospheric sea level pressure field: the former is observed for the winter-spring season and the latter for the summer-autumn. In the cold part of the year, due to the positive temperature contrast between sea and land, a low-pressure system is formed over the Black Sea. During the warm period an anticyclonic circulation is observed over western part of Black Sea, leading to an eastward extension of the Azore maximum. Analysis of climatological data of annual variations of mean wind stress curl over the Black Sea region reveals cyclonic anomalies during the cold period and anticyclonic anomalies during the warm months [14].

In winter months (January, February and March) the Rim Curent is strong and narrow without any significant lateral variations. This is due to the stronger winter winds. The inner cyclonic zone consists of two well developed gyres (Eastern and Western ones). The stronger winter conditions the stronger the Rim Current. In summer (July, August, September) Rim Current weakens and diffuses. The two-gyres inner pattern trasforms into one composite cyclonic cell. In early autumn (October) the Rim Current becomes hardly noticeable and inner area is completely disintegrated into small cyclonic cells. The reverse process of integration starts in the late autumn (November, December) [4]. The mesoscale features like anticyclonic outer eddies and meanders mostly exist late winter to the early autumn. For example the Batumi gyre, one of the most persistent cells, forms in the early March and lives to the end of October. The only exception of this rule is the Sukhumi gyre, which forms when the Batumi eddy is over, and lives until it is formed again. Later it is absorbed by the Batumi gyre [4]. The horizontal sizes of the largest well-developed anticyclonic gyres are about 100-150 km; the vertical dimension is up to 1000 m [3].

Although the quasi-stationary mesoscale eddies have been a subject of investigation of many studies [2, 4–9] still lots of uncertainties exist about their evolution and propagation. This paper aims to investigate the formation and evolution of the Batumi eddy during the year using satellite altimeter data. Similar approach is used in [10].

2. DATA USED IN THE STUDY

The present paper uses altimeter data reprocessed by Copernicus Marine Environment Monitoring Service (CMEMS) downloaded from http://marine.copernicus.eu. This product is processed by the SL-TAC multimission altimeter data processing system. It processes data from all altimeter missions: Jason-3, HY-2A, Saral/AltiKa, Cryosat-2, Jason-2, Jason-1, T/P, ENVISAT, GFO, ERS1/2. It includes gridded sea surface height anomalies and derived geostrophic current velocities anomalies. The anomalies have been taken with respect to the 20-year means (1993–2012). The used data covers the period from January 1993 to December 2015. During this 23-year period there have been many missions (mentioned above) and they all have been homogenized with respect to a reference mission which is currently OSTM/Jason-2. The spatial resolution is 0.125º / 0.125º (about 10 km) and the time resolution is daily. The maps are calculated with all the satellites available (up to 4 satellites) for each date. The standart corrections have been made and data have been filtered from small scale signals [11].

3. SEASONAL VARIATIONS OF THE SEA LEVEL HEIGHT ANOMALY

As we are interested in the horizontal variability, the first step is to exclude the effect of the mean sea level variability. The latter is due to the contribution of water fluxes (river discharges, evaporation, precipitation, strait fluxes) and steric effects. According to [13] this type of variability is about 85% of the total variance of the Black Sea level. The calculated area average daily sea level height anomaly is given in Fig. 2. It reflects the tendency for increase in the last decade of 20th century, followed by relative stability and periodic oscillations. The derived mean is then substracted from actual SLA for each grid point. This correction is based on assumption that the response of sea level to these volume fluxes is almost uniform over the Black Sea area.

The daily maps of the SLA are averaged to obtain monthly mean horizontal maps and seasonal averages. The seasons are considered as follows: winter – January, February and March; spring – April, May and June; summer – July, August and September; and autumn – October, November and December.

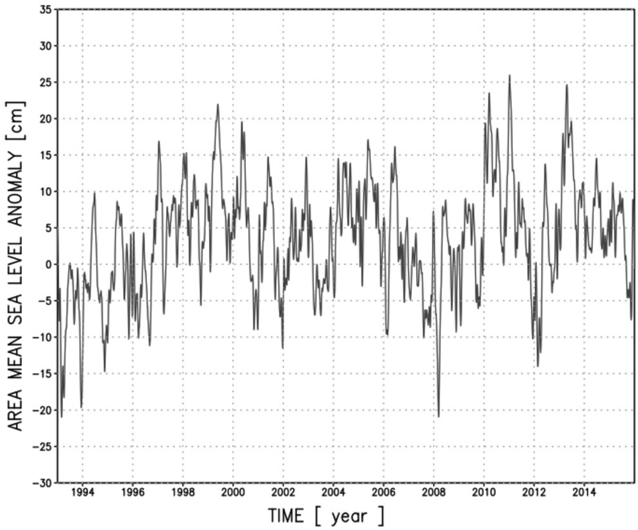

Fig. 2. Daily area mean sea level height anomaly [cm] for the period 1993–2015

The monthly mean maps for SLA are shown in Fig. 3 for each month. They reveal a significant intensification of the cyclonic circulation in winter and weakening during summer, this result is in accordance with the earlier studies findings. The anticyclonic eddies gather strength during spring season, achieve maximum severity in summer and later lose momentum. The most interesting feature in the eastern basin is the tripole structure with Batumi eddy in the easternmost end, which changes the anomaly sign seasonally. During the cold part of the year (December to March) Batumi eddy presents negative (cyclonic) anomaly; and in the warm part (June to September) – positive (anticyclonic) anomaly. Furthermore, this is accompanied with the alternating anomalies along the eastern Black Sea coast. In the transition period (spring April–May) a slight positive anomaly replaces the negative one and pushes it north-westward gaining momentum. The same process with the opposite sign occurs in the other transition period (autumn October–November).

The Batumi eddy reveals the most prominent anual amplitude. Acording to [4] the Batumi eddy is absent in winter months. Our analysis shows cyclonic anomaly during winter, so the Batumi eddy (which is considered anticyclonic) almost disappears. In this region we estimated SLA anual amplitude of 16 cm and the anticyclonic eddy is most pronounced in September.

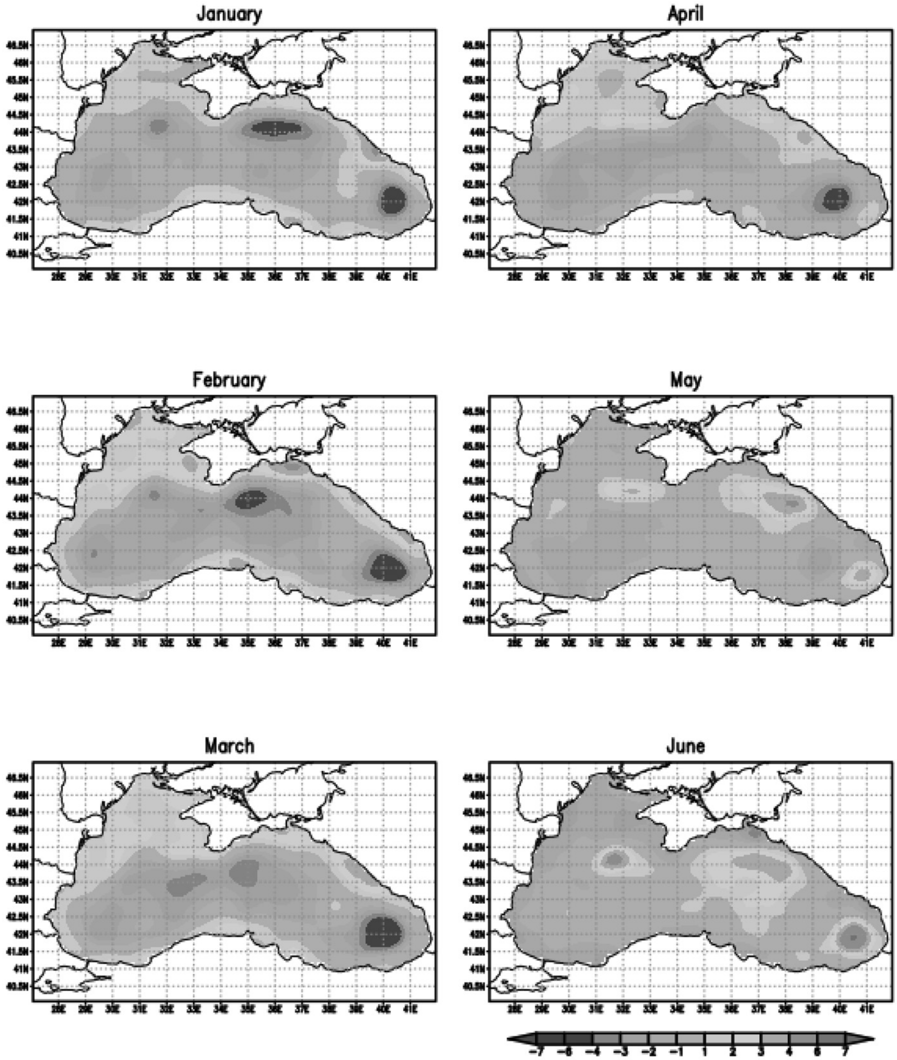

Fig. 3. Monthly mean sea level anomaly maps [cm] January to June, derived from averaged altimeter data for the period 1993–2015

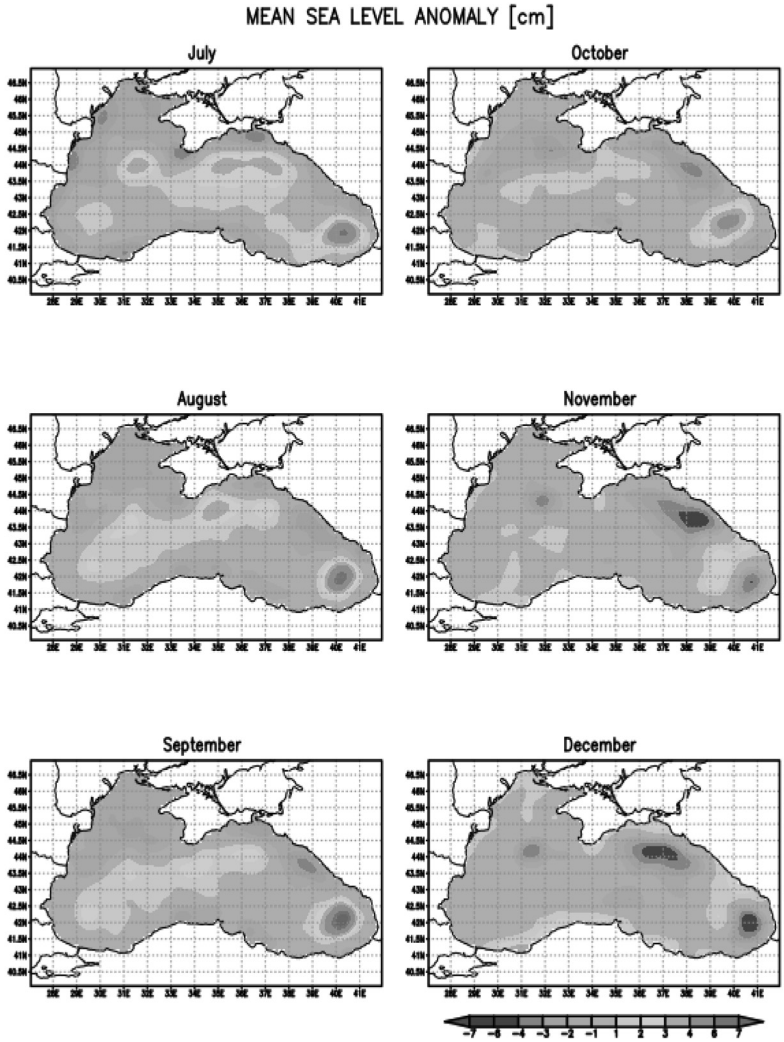

Fig. 3. (continued) Monthly mean sea level anomaly maps [cm] July to December, derived from averaged altimeter data for the period 1993–2015

The above described process is very well seen in the seasonal maps of the geostrophic current anomaly (Fig. 4). The geostrophic velocity anomaly is derived from the sea level height anomaly. The Rim current and the anticyclonic eddies along the coast are easily distinguished. Winter and summer circulation show similar patterns with opposite sign: cyclonic anomaly of the Rim current and Batumi eddy in winter and anticyclonic – in summer. The transition between these two stages begins with the appearance of small opposite-sign anomaly near Georgian coast, which slowly pushes the main eddy north-westward, takes its place and grows. The meanders of the Rim current exibit a wave pattern which leads to the conclusion of wave propagation and will be discussed in the next chapter. We have to note that similar process (less intensive) could be observed in the Sevastopol eddy area in the Western Black Sea basin.

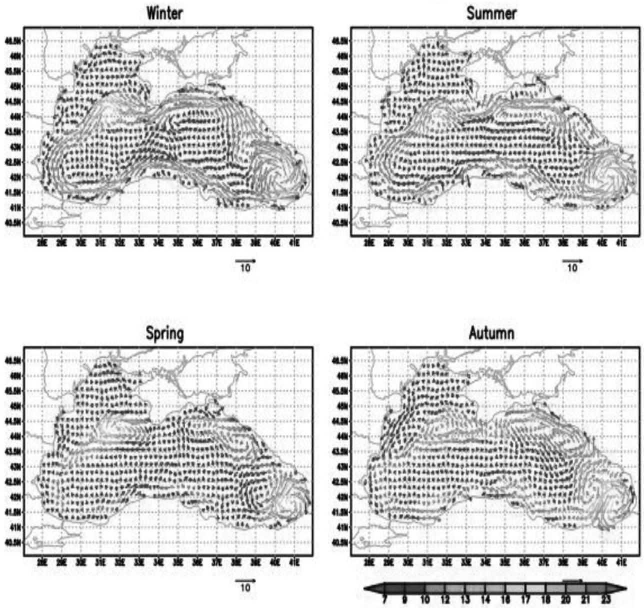

Fig. 4. Seasonal mean geostrophic velocity anomaly [cm/s] maps for the period 1993–2015

4. SEASONAL SIGNAL PROPAGATION ALONG THE EASTERN BLACK SEA COAST

In order to track the possible wave propagation of the seasonal SLA signal we have constructed a Hovmoller diagram of the monthly SLA fields along the cross-section AB (Fig. 5). The line AB is drawn to cross the eastern basin passing through the approximate centers of the tripole structure, extending from the Batumi area to the Eastern Crimean region.

The Hovmoller diagram for the monthly SLA for the whole regarded period 1993–2015 along the cross-section AB is plotted in Fig. 6 (left). There is an evidence of a propagating pattern from southeast to northwest. At most locations the SLA changes alternatively the sign in time: positive anomaly in summer, negative – in winter. This is especially pronounced in the easternmost part (40E–41E). The right plot in Fig. 6 is a zoom over the period 2012–2015 in order to better visualize the described above process. This allows us to approximately calculate the wave propagation speed – in an order of 1 cm/s.

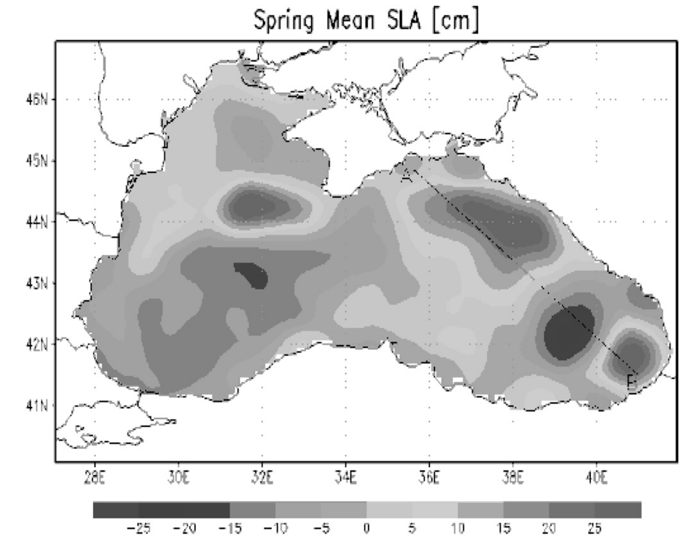

Fig. 5. Seasonal mean SLA [cm] for spring and the chosen cross-section AB

In this paper our objective is to show what is observed in the eastern Black Sea using altimeter data and not to search a theoretical explanation and quantification of the process. There are previous studies of the Black Sea circulation based on numerical simulations, which associate the alternating cyclonic and anticyclonic eddies to Rossby waves and basin modes [reference 6, 7, 12]. Our future plans include to further investigate the described above process in order to study the controlling physical mechanisms.

5. CONCLUSIONS

The Black Sea circulation reveals seasonal and interannual variability which have been studied for a long time. In winter months (January, February and March) the Rim Curent is strong and narrow without any significant lateral variations, due to the stronger winter winds. The mesoscale features like anticyclonic outer eddies and meanders mostly exist late winter to the early autumn. Although the quasi-stationary mesoscale eddies have been a subject of investigation of many studies, still lots of uncertainties exist about their evolution and propagation. In this paper we investigate the formation and evolution of eddies in the eastern Black Sea basin during the year using satellite altimeter data.

We use Copernicus Marine Environment Monitoring Service (CMEMS) multi-mission altimeter data product, which combines data from Jason-3, HY-2A, Saral/AltiKa, Cryosat-2, Jason-2, Jason-1, T/P, ENVISAT, GFO, ERS1/2. It includes gridded sea surface height anomalies and derived geostrophic current velocities anomalies.

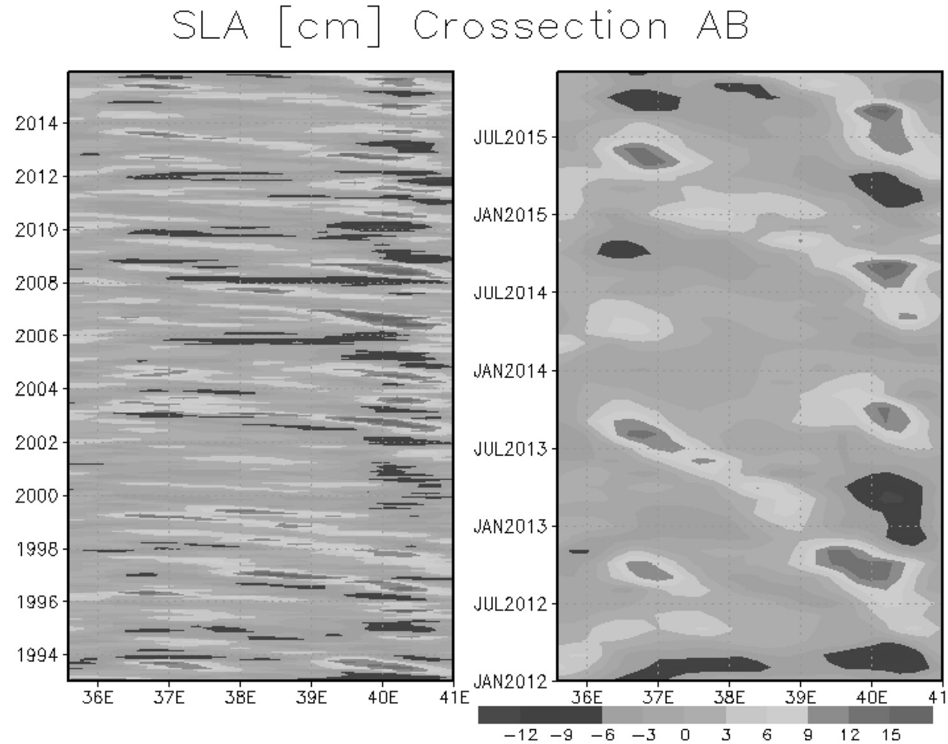

Fig. 6. The left plot shows monthly SLA [cm] for the period 1993–2015 along the cross-section AB. The right plot shows the same for the 4-year period 2012–2015 for better visibility

The anomalies have been taken with respect to the 20-year means (1993–2012). The used data covers the period from January 1993 to December 2015 with spatial resolution of 0.125º / 0.125º (about 10 km) and the time resolution is daily.

The first step of the analysis is to subtract the sea level signal associated with the water fluxes and steric effect. This is done in order to focus on the spatial variations. Then the daily SLA maps are averaged to obtain the monthly and seasonal mean maps.

The most interesting feature in the eastern basin is the tripole structure with Batumi eddy in the easternmost end, which changes the anomaly sign seasonally. Winter and summer circulation show similar patterns with opposite sign. During the cold part of the year (December to March) Batumi eddy presents negative (cyclonic) anomaly; and in the warm part (June to September) – positive (anticyclonic) anomaly. The transition between these two stages occurs in April-May and October-November: it begins with the appearance of small opposite-sign anomaly near Georgian coast, which slowly pushes the main eddy north-westward, takes its place and grows. Similar process is observed in the Sevastopol eddy area in the Western Black Sea basin.

We have analyzed the SLA along cross-section passing through the eastern basin. The Hovmoler diagram shows evidence of a propagating seasonal signal in the direction southeast-northwest with approximate speed of an order of 1 cm/s.

Previous studies based on numerical simulations associate such propagating eddies to Rossby waves and basin oscillations. Future investigation is planned in order to reveal the physical mechanism controlling the observed processes.

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