SEASONAL VARIATIONS OF THE MARINE AND ATMOSPHERIC CIRCULATION IN THE BLACK SEA BASIN

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Abstract: *The multi-mission altimeter data for the Sea Level Anomaly (SLA), processed and distributed by Copernicus Marine Environment Monitoring Service, and the meteorological reanalisys of ECMWF ERA-Interim data are used to compare the seasonal variability of the Black Sea circulation and the atmosphere circulation above the basin. The seasonal averaged maps of the SLA, geostrophic current anomaly, mean sea level pressure, the wind velocity and curl reveal an accordance between the rotation of the atmosphere and sea circulation in the Eastern Black Sea area. The winter positive wind curl area, centered over the inner part of the basin, explains the winter intensification of the Rim Current. The summer configuration of wind curl could explain the spring-summer intensification of the Batumy anticyclonic eddy and the negative SLA near the Caucasus coast.*
KEYWORDS*: BLACK SEA, CIRCULATION, EDDY, CURRENTS, WIND, ROTATION, SEASONAL VARIABILITY*

1. Introduction

The Black sea upper level circulation has been a subject of investigation of many studies and has been estimated by different methods. It is characterized by a basin-wide cyclonic boundary gyre known as Rim Current. Within this current, two or more smaller cyclonic cells are formed. 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, meanders and filaments spread over the basin. The Rim Current separates the cyclonically dominated inner zone from the anticyclonically dominated coastal area [1, 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.

The surface circulation in the Black sea reveals seasonal and interanual variability [2,3,4]. In our previous work [3] we investigated the seasonal variations of the sea level anomaly along the eastern Black Sea coast and found that a tripole structure with Batumi eddy in the easternmost end exists and changes the anomaly sign seasonally. The objective in this study is to relate the processes occurring in the sea with the atmospheric circulation. Such a relation is identified by other authors: in the study [4] ERA-40 data are used for the first months of the seasons (January, April, July and October). According to their results there are two basic patterns of sea level pressure field: one for the winter-spring and the other for the summer-autumn. We use the seasonal averaged atmospheric pressure, winds and the wind rotation.

2. Data used in the study

To study the circulation of the Black sea we used 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, Sentinel-3A, 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 [5].

For pressure and wind fields we used the ERA-Interim reanalize processed by ECMWF. The data covers the period 1993-2015 year. The spatial resolution is 0.75º / 0.75º (about 80 km). [6, 7]

3. Seasonal variations of upper layer circulation

The seasons are considered as follows: winter – January, February, March; spring – April, May, June; summer – July, August, September; winter – October, November, December. The seasonal averaged maps of the sea level anomaly (SLA) and streamlines of the geostrophic velocity anomalies are given in Fig. 1. In winter there are negative anomalies in the inner region of the Rim Current and positive ones during the summer. Consequently there is an intensifying of the cyclonic circulation during the winter and easing during the summer. The winter and summer Black Sea circulation show similar patterns of currents with opposite sign: cyclonic direction of the Rim current, Batumi eddy and Kerch eddy in winter and opposite direction in summer. The transition between these two states begins with an appearance of weak negative anomaly near the Georgian coast, which grows and pushes the positive anomaly in northwestern direction and replaces it growing further. Similar processes are observed also in the Western basin in the region of the Sevastopol eddy, but less intense. The most prominent feature in the seasonal averaged SLA maps is the triple structure (tripole) in the eastern Black sea basin, involving the Batumi eddy in the easternmost end. It changes the sign from the warm to the cold part of the year. During the months December to March Batumi eddy is identified by a negative (cyclonic anomaly). During the warm part of the year (June to September) the Batumi eddy presents a positive (anticyclonic) anomaly. This is valid for the tripole, changing periodically the sign along the coast in the north-western direction. The transition occurs in April-May when the weak positive anomaly replaces the negative one and moves the whole structure northwestward. Similar transition with opposite sign happens in the autumn (October-November).

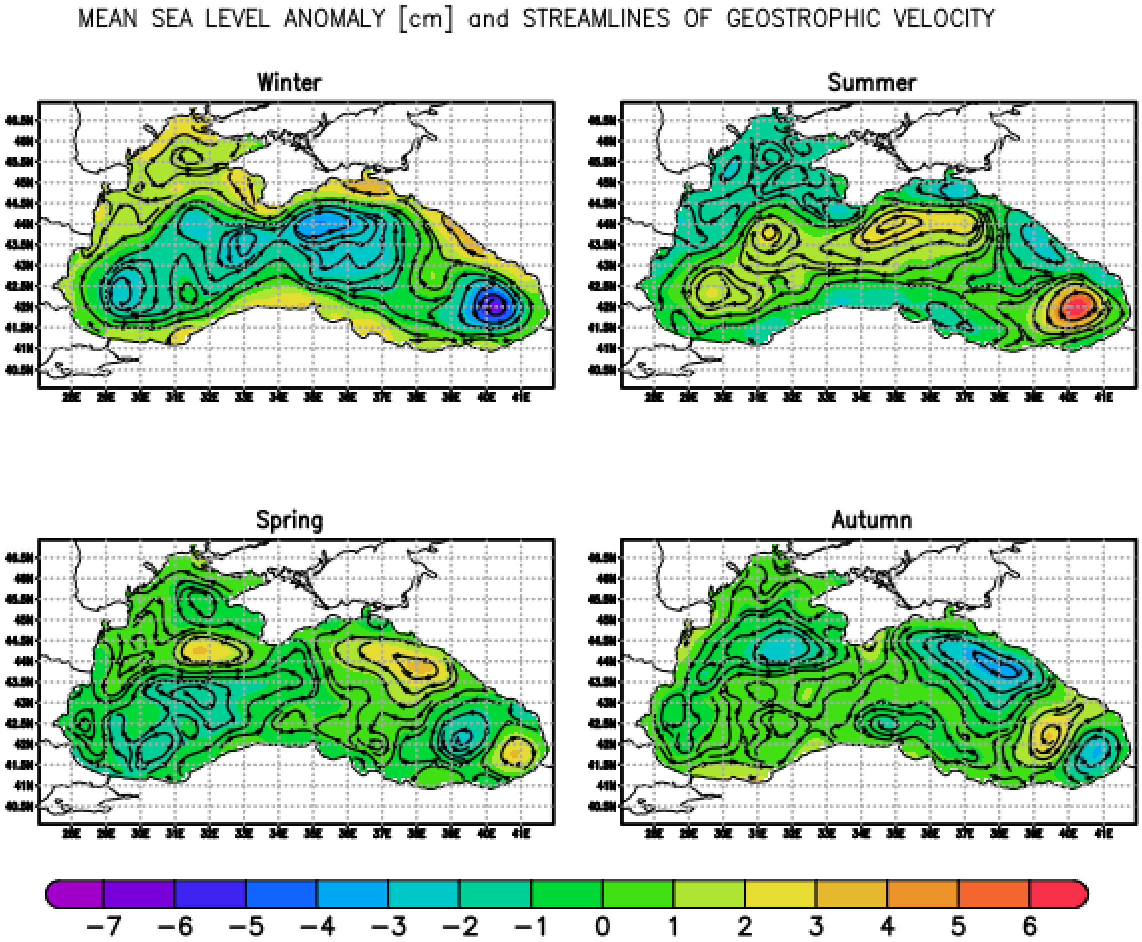

***Fig.1**. Seasonal maps of the sea level anomaly and the streamlines of the derived geostrophic velocity for the period 1993-2015*

4. Investigation on the atmospheric circulation over the Black sea

Noting the significant seasonal variability in the Black Sea circulation a question arises whether it is related to the seasonal variations in the atmospheric circulation in the region. The data for the atmosphere circulation is taken from the ERA-Interim meteorological reanalysis and include the mean sea level pressure and surface winds.

The 2D fields of the mean sea level pressure are averaged over the seasons in the same way as for the SLA and the obtained maps are shown in Fig. 2. Two basic configurations could be identified – autumn-winter and spring-summer configurations. The autumn-winter pattern is characterized by a depression situated over the central part of the sea. During the spring the configuration of the pressure field changes: the depression moves to the east. In the summer months over the western part of the Black sea an anticyclonic field forms, but over the Eastern Black Sea and Caucasus Mountain there is a deep depression. This depression is intense and stronger than in any other season. However, the comparison between Fig. 1 and Fig. 2 shows not much similarity bringing to the conclusion that the pressure variability is not the main factor explaining the seasonal variations of the marine eastern basin circulation.

In Fig. 2 we show also the seasonal averaged wind fields. Comparing the seasons the most pronounced difference is along the south coast in the eastern basin. In winter and autumn a wind swirl over the easternmost regions is observed, and along the south coast the wind is from west or southwest. During summer and spring this swirl is not present, and the wind along the south coast is northwest. The eastern basin is surrounded by high mountains of the Caucasus and the Anatolian Plate. Thus the northwest wind is trapped in the eastern basin.

In order to show better this atmospheric circulation feature we give in Fig. 3 the seasonal wind curl. The winter and autumn maps show stronger cyclonic curl in the Black Sea inner part which explains the winter Rim current intensification. Over the Western basin in winter and autumn the wind curl is cyclonic, and in the other part of the year it is predominantly anticyclonic. Regarding the Eastern basin it is evident that the wind rotation the Eastern Black Sea is always positive (cyclonic) over the central part and negative (anticyclonic) in the south, however there are changes from season to season. In summer the cyclonic area is extended towards northeastern continent and presents the maximal value up to +25 x 10^{-6} s^{-1}. On the contrary, the southernmost part is occupied by a large anticyclonic wind curl of about -10 x 10^{-6} s^{-1}. This configuration could explain the eastern dipole in the sea: intensification of the Batumy anticyclonic eddy and the negative SLA near Caucasus coast. This anticyclonic area weakens in the other seasons.

The comparison of the Fig. 1 and Fig. 3 leads to the conclusion that some characteristics of the seasonal sea circulation could be explained by the atmospheric factors, but not the whole observed picture.

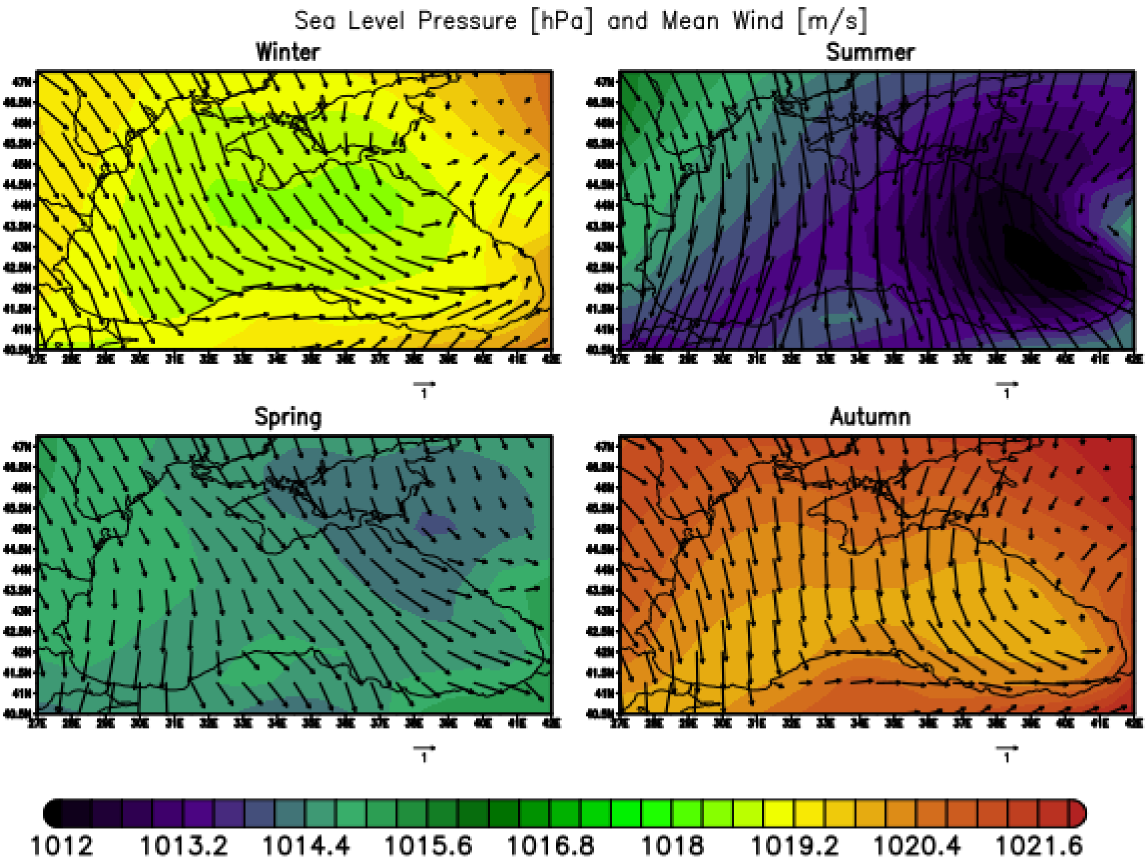

Fig. 2. *Seasonal maps of the mean sea level pressure and surface winds during the period 1993–2015.*

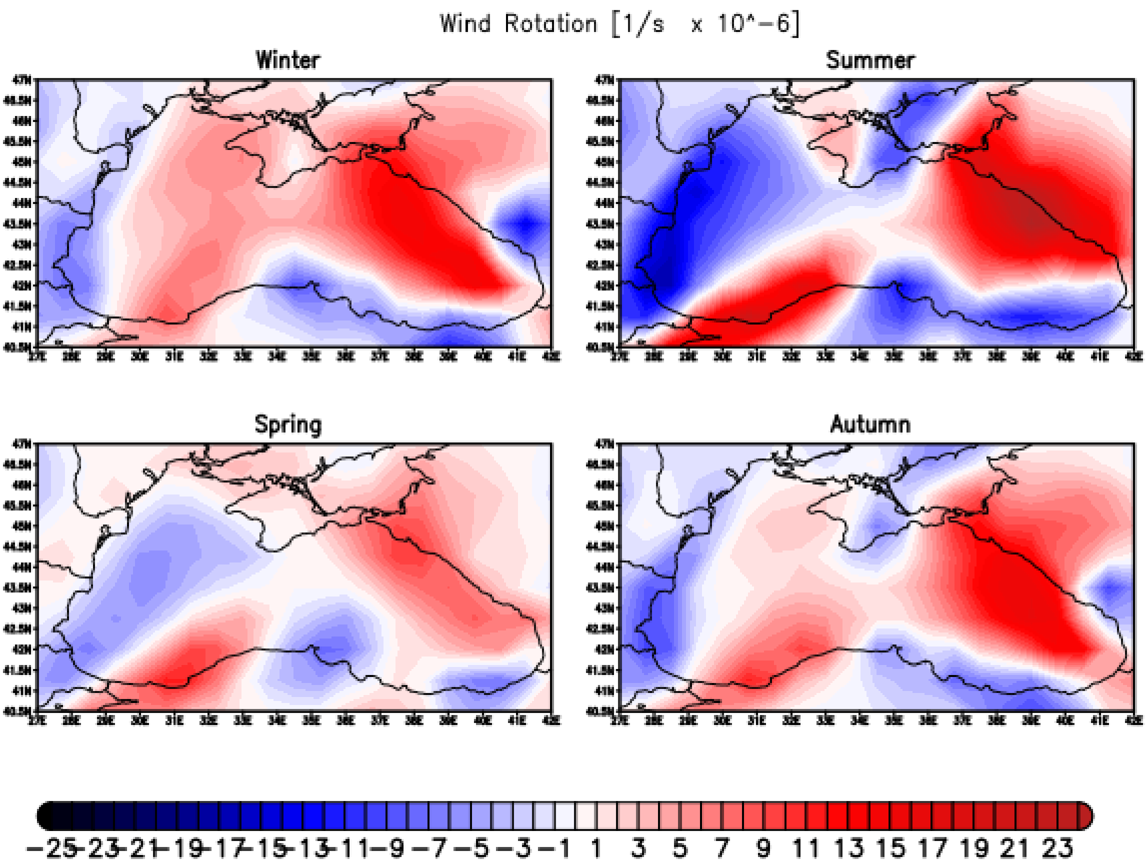

Fig. 3. *Seasonal maps of wind curl [10^{-6} s^{-1}] during the period 1993-2015 years.*

5. Conclusions

The Black Sea circulation exhibits seasonal variability which have been a subject of many studies. Our previous studies has found the existence of triple structure (tripole) in the Sea Level Anomaly (SLA) in the Eastern Black Sea basin, involving the 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. To investigate this we used altimetry data from Copernicus Marine Environment Monitoring Service (CMEMS). It includes gridded sea surface height anomalies and derived geostrophic current velocities anomalies. The used data covers the period from January 1993 to December 2015. The daily maps are averaged to obtain seasonal mean maps of SLA and streamlines of derived geostrophic velocity. Further we examined the seasonal variations in the atmospheric circulation in the region with a goal to find a relation. The data for the atmosphere circulation have been taken from the ERA-Interim meteorological reanalysis and include the mean sea level pressure and surface winds. It covers the same period as the altimeter data. We obtained seasonal maps of pressure, wind field and wind curl.

The autumn and winter maps reveal stronger cyclonic curl in the Black Sea inner part which explains the winter Rim current intensification. The spring and summer maps show different behavior of wind curl in the two parts of the Black sea. Over the Western basin the wind curl becomes predominantly anticyclonic. Over the Eastern basin the most notable feature is positive (cyclonic) wind curl over the central part and negative (anticyclonic) in the southernmost end. In summer the cyclonic area is extended over northeastern coast and has its largest values. The anticyclonic area becomes more intensive, larger and covers the region of Batumy eddy. This configuration could explain the eastern dipole in the sea: spring-summer intensification of the Batumy anticyclonic eddy and the negative SLA near Caucasus coast. This anticyclonic area weakens in the other seasons.

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