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CURRENT FIELD VARIATIONS IN THE NORTH-WESTERN SIDE OF THE BLACK SEA

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ABSTRACT

The objective of the present work is to provide a better understanding of the current patterns in the North-Western part of the Black Sea basin. This is made considering satellite data that contain gridded current fields with daily measurements at the sea surface. In this matter, the current data were analyzed in 16 reference points for a period of 18 years (1992-2010). Statistical analyses concerning the current variation in time, both as regards their velocities and directions are presented for the considered reference points.

Keywords: Black Sea, current patterns, current directions, satellite data

1. Introduction

The objective of the present paper is to analyze the circulation patterns in the North-Western part of the Black Sea.

Black Sea is the second biggest enclosed sea on Earth, after Caspian Sea. Situated between Europe, Anatolia and the Caucasus and bounded by the following geographic coordinates: latitude 40.56°N and 46.33°N, 27.27°E and 41.42°E longitude, the Black Sea has a surface of 423.000 km^2, with a maximum depth of about 2588 meters (however depths this high are isolated cases, the general depth being considered to be around 2100 m). The Black Sea is surrounded by six countries: Romania, Bulgaria, Turkey, Georgia, The Russian Federation and Ukraine, countries that share together 4340 km of coast. The average annual discharge of the rivers in the Black Sea is of 300km^3 per year, most of this water coming from the Danube, Dniepr and South Bug [1]. Its only connection with the Global Ocean is made by a channel of 0.7-3.5 km width and 31 km long, called the Bosphorus Strait. The strait links the Black Sea with the Mediterranean Sea, via the Sea of Marmara. Black Sea contains two types of currents, one of them being formed by the Bosphorus Strait causing an exchange of water between the Black and Marmara Sea. This particular type of current is characterized by the fact that the less saline water from the Black Sea flow at the surface into the Marmara Sea at a speed of a maximum of 2 ms^{-1}. At the same time the more saline denser waters of the Marmara Sea flow at a depth of 50-120 m with a speed of 2-4 ms^{-1} into the Black Sea. There should also being mentioned the current formed by the Kerch strait where at the surface there is an exchange of water from the Azov Sea with a speed of 1-2 ms^{-1} while the lower currents flows from the Black to Azov Sea at a depth of 5 meters. The other type of currents is created by the cyclonic pattern of the wind field. It consists of two closed circles, the western one that opposes the Danube Delta and reaches 100 km and the eastern cycle that varies between 50 and 100 km. Due to the anoxic characteristic of approximately 90% of the Black Sea's water, the vertical currents, while they exist, they have small values at higher depths, not exceeding $0.05ms^{-1}$.

The proposed work aims to analyze the time variation of the currents in the North-Western part of the Black Sea. In this regard, 16 points were considered for analysis for a period of 18 years, (1993 to 2010). The points were chosen between 29-33˚E longitude and 44-46˚N latitude. Statistical analyses along with rose-type graphics were performed in order to determine the general characteristics of the current field in this area.

2. GENERAL CIRCULATION PATTERNS FOR THE ENTIRE BLACK SEA BASIN

According to Enriquez [2], the Black Sea is vertically stratified into three layers. The first one is the surface mixed layer and it ranges up to 50 meters. Its general characteristic is that responds strongly to seasonal temperature and wind variations. The second layer is the intermediate cold layer, ranging from 50 to 180 or 200 meters, with a maximum temperature between 6˚C and 8˚C. Below the intermediate cold layer is the bottom layer that contains anoxic waters. While the waters in the first two layers mix, there is not the case for the bottom layer. Here even the water salinity is different with values of an average 22 PSU compared to a much lower value of 18 PSU in the upper layers. The lower value of the salinity in the upper layers is considered to be because of the river discharges, rain and water dilution [3].

In Figure 1, a generalized scheme of the circulation is presented, according to Titov *et al.* (2008). The main structural element presented in the Figure 1 is Rim Cyclonic Current (RCC) which crosses the entire basin. RCC is responsible for the cyclonic general water transport in the Black Sea basin.

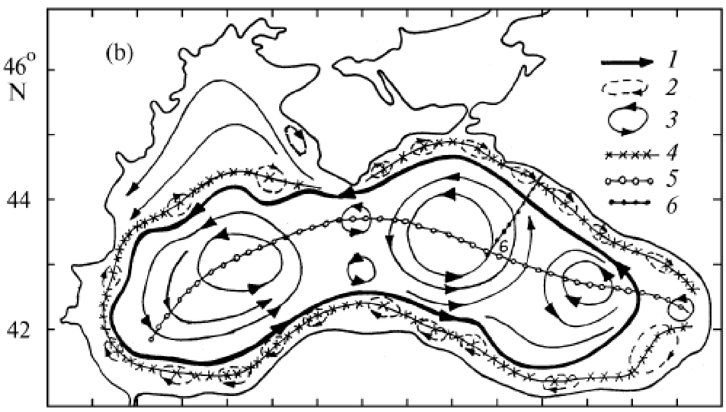

Fig. 1. A generalized scheme of a general circulation of the Black Sea: (1) RCC midstream; (2) near-shore anticyclonic eddies (NAE); (3) centers of quasi-stationary cyclonic gyres; (4) a zone of near-shore anticyclonic vorticity of the current field (NAV); (5) a central divergence zone (CDZ); (6) a standard long-term hydrological section [8]

The Rim Cyclonic Current stability can be observed in its meanders. The middle section meanders move from their average position towards onshore and offshore. The middle section of the Rim Current can travel close to the coastal zone with a distance of 8-10km and move further from it with 80-100km. Meanders cycles can vary from 6 to 10 days. A regularity can be observed in the disposal of the relative eddies in the middle area of the Rim Current. Nearshore anticyclonic eddies are formed at the right border of the Rim Current and at the left border cyclonic eddies appear. Eddies are formed in meanders apexes: nearshore anticyclonic eddies will be formed in the acute angle anticyclonic meanders bent with the peak directed towards the sea while cyclonic eddies in acute angle cyclonic meanders bents with the peak directed towards land. The eddies forming, found at the lateral border of the Rim Current, happens due to vorticity in the bent meander and on a lateral tilt of current speed, as comments by Toderascu and Rusu [7].

As concerning the wave modeling for the Black Sea, the authors recommend the works of Rusu [4] and Rusu and Ivan [5]. An implementation of a circulation model for the Black Sea basin was also presented in Toderascu and Rusu [6].

3. STATISTICAL ANALYSIS

For a better understanding of the current variations in both space and time in the North-Western part of the Black Sea, satellite data for a period of over 18 years were analyzed. The satellite data were obtained from Aviso website (http://www.aviso.oceanobs.com/en/). 16 points were considered for the analysis of the current data, chosen between 29-33˚E longitude and 44-46˚N latitude. Figure 2 shows the bathymetric map of the entire Black Sea along with a selection of the analyzed area, while Figure 3 shows the selected area with the 16 considered points.

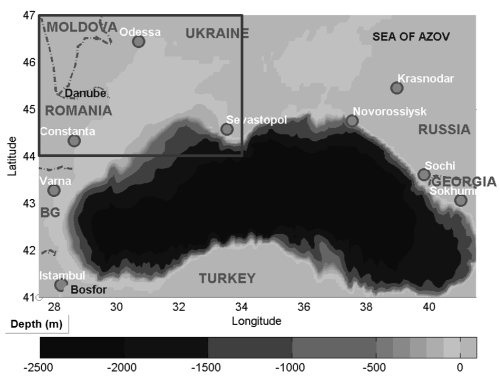

Fig. 2. The bathymetric map of the Black Sea with the coastal sector considered for analysis

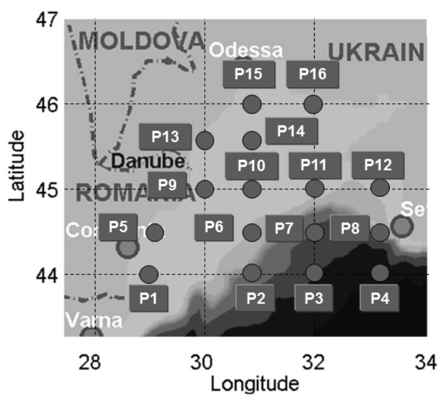

Fig. 3. The location of the 16 considered points.

Table 1 presents the coordinates of the analyzed points and the median values of the current velocity on each of the 12 months. Table 2 shows some statistical analyses performed on the 16 points. The statistical analysis consists for this case in: minimum, maximum, mean, median, standard deviation, skewness and kurtosis, as well as the number of analyzed points.

Kurtosis represents the relative concentration of the data in the center versus the tails of a frequency distribution when it is compared with the normal distribution. The normal distribution has a value of 3. This is equal to the fourth power of the standard deviation of the distribution minus 3.

$$Kurt = \frac{\mu_4}{\sigma^4} - 3. \quad (1)$$

Table 1. Monthly median values of current velocity for each point (ms^{-1}).

Points location	**Month**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
P1 (44N, 29E)	0.07	0.07	0.07	0.06	0.07	0.06	0.07	0.06	0.07	0.08	0.08	0.07
P2 (44N, 31E)	0.15	0.15	0.14	0.16	0.14	0.16	0.14	0.15	0.13	0.14	0.14	0.12
P3 (44N, 32E)	0.15	0.14	0.16	0.18	0.17	0.16	0.15	0.12	0.13	0.14	0.12	0.14
P4 (44N, 33E)	0.13	0.12	0.14	0.13	0.11	0.09	0.10	0.10	0.11	0.11	0.11	0.11
P5 (44.5N, 29E)	0.08	0.07	0.06	0.06	0.06	0.05	0.09	0.08	0.07	0.09	0.08	0.08
P6 (44.5N, 31E)	0.11	0.12	0.13	0.12	0.11	0.12	0.10	0.09	0.09	0.09	0.10	0.12
P7 (44.5N, 32E)	0.16	0.17	0.19	0.15	0.14	0.16	0.13	0.11	0.14	0.13	0.15	0.15
P8 (44.5N, 33E)	0.10	0.10	0.10	0.09	0.09	0.09	0.10	0.09	0.11	0.11	0.11	0.11
P9 (45N, 30E)	0.08	0.09	0.07	0.06	0.07	0.07	0.09	0.08	0.08	0.08	0.08	0.07
P10 (45N, 31E)	0.07	0.08	0.07	0.07	0.05	0.06	0.07	0.05	0.06	0.07	0.07	0.07
P11 (45N, 32E)	0.08	0.08	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.08	0.07
P12 (45N, 33E)	0.07	0.07	0.06	0.06	0.06	0.05	0.06	0.07	0.07	0.07	0.08	0.07
P13 (45.5N, 30E)	0.08	0.08	0.08	0.07	0.08	0.08	0.09	0.08	0.08	0.08	0.09	0.07
P14 (45.5N, 31E)	0.07	0.08	0.06	0.06	0.06	0.06	0.07	0.08	0.07	0.07	0.07	0.07
P15 (46N, 31E)	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.07	0.07	0.08	0.06
P16 (46N, 32E)	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07

Table 2. Statistical analyses for the considered points

Nr. of data points 6672	Min (ms^{-1})	Max (ms^{-1})	Mean (ms^{-1})	Median (ms^{-1})	St. Dev (ms^{-1})	Skewness	Kurtosis
P1	0.00	0.29	0.07	0.06	0.04	1.12	5.26
P2	0.00	0.48	0.14	0.13	0.08	0.86	3.63
P3	0.00	0.56	0.15	0.13	0.08	0.99	4.41
P4	0.00	0.49	0.11	0.10	0.07	1.21	5.16
P5	0.00	0.31	0.07	0.06	0.05	1.15	4.70
P6	0.00	0.43	0.11	0.10	0.06	0.92	4.13
P7	0.00	0.57	0.15	0.14	0.08	1.02	4.62
P8	0.00	0.34	0.10	0.09	0.06	0.78	3.57
P9	0.00	0.36	0.08	0.07	0.05	1.27	5.49
P10	0.00	0.30	0.07	0.06	0.04	1.11	4.99
P11	0.00	0.28	0.07	0.06	0.04	1.28	5.53
P12	0.00	0.32	0.06	0.06	0.04	1.34	6.17
P13	0.00	0.30	0.08	0.07	0.05	1.10	4.60
P14	0.00	0.33	0.07	0.06	0.04	1.08	5.01
P15	0.00	0.32	0.07	0.06	0.04	1.16	5.20
P16	0.00	0.37	0.07	0.06	0.04	1.56	7.94

Standard deviation in statistical analysis measures the data dispersion from the mean value:

$$\mathrm{Std} = \sqrt{\mathrm{E}\left[(\mathrm{X} - \mu)^2\right]}, \quad (2)$$

with μ=E[X] being the mean value, where E is the expectation operator. X represents a discrete random variable with the probability mass function p(x). According to formula 2, the expected value will be:

$$E(X) = \sum x_i p(x_i). \tag{3}$$

Skewness is a measure of the symmetry distribution in a data set. The skewness value can be positive, negative or undefined. The skewness of a variable X is defined as the third standardized moment as follows:

$$\text{Skew} = \frac{\mu_3}{\sigma^3}, \tag{4}$$

where μ_3 is the third moment above the mean and the k^{th} moment about the mean is defined as:

$$\mu_k = E\left[(X - E[X])^k\right] \tag{5}$$

4. CURRENT VARIATIONS BY DIRECTION

In order to evaluate the current velocity distribution by direction, rose-type graphics were designed for 4 points: P2, P3, P8, and P14. The graphics were made for winter and summer time, respectively, where winter is considered to be the 6 months period from October to March while summer the remaining 6 months from April to September. Figure 4 shows the directional distribution for the currents corresponding to the reference point P2, while Figures from 4 to 6 the same representations for the points P3, P8 and P14, respectively.

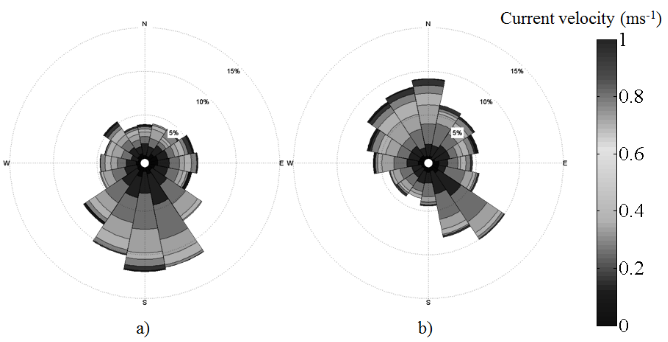

Fig. 3. Current distribution in P2: a) winter time, b) summer time

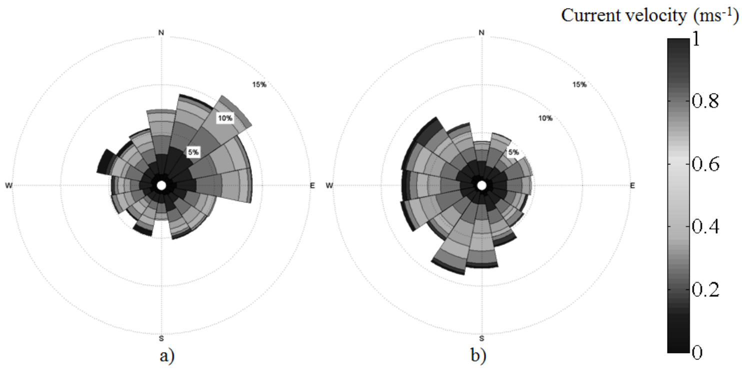

Fig. 4. Current distribution in P3: a) winter time, b) summer time

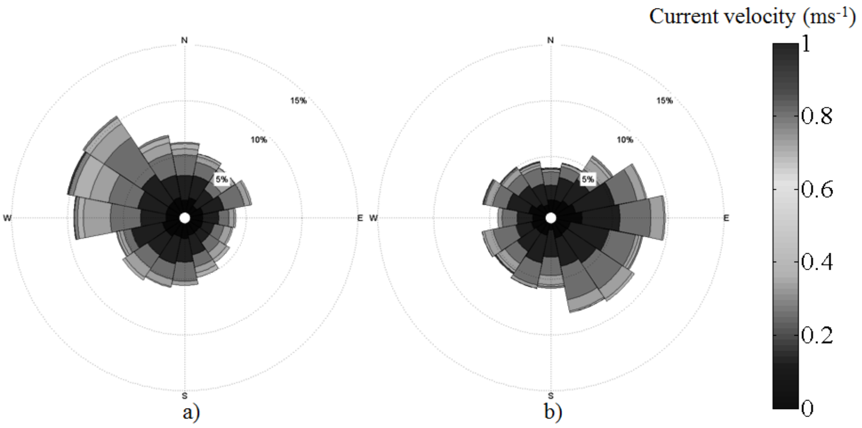

Fig. 5. Current distribution in P8: a) winter time, b) summer time

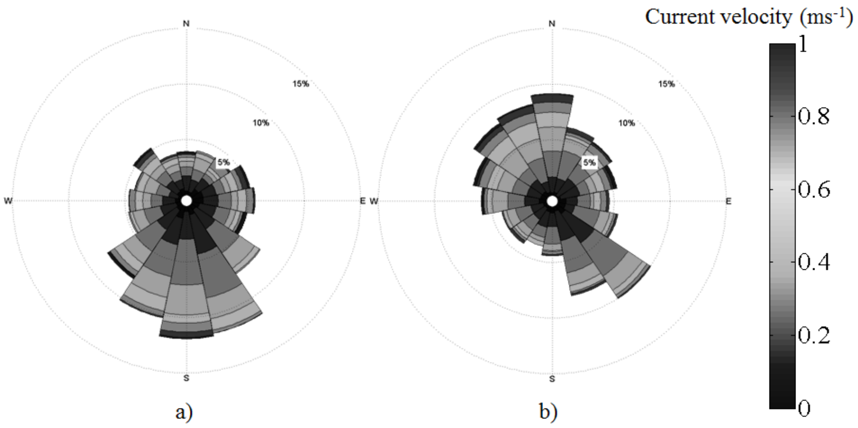

Fig. 6. Current distribution in P14: a) winter time, b) summer time

As it can be observed in Figures 3 to 6, the current direction presents strong seasonal variations. For the point P2 there is a strong South orientation for winter time, while in the summer there is a North-West orientation, as well as a South-East one. For P3, the winter season presents a clear North-East component, while in the summer a North-West and South-West components appear. The same cases also repeat for P8 and P14. While for P8 in the winter time there is a clear North-West component, in the summer there is not a clear direction, North-East, South-East. As for P14 there is a clear South direction in the winter time, while for summer there are two major components: North-West and South-East. In all the 4 investigated cases, the winter time presented a strong directional component with small variations over other direction, while the summer time seems to be characterized by a state of instability regarding the direction. In all the cases a major directional orientation can hardly be identified for the summer time.

5. CONCLUSIONS

The present work provides some insight regarding the current patterns in the North-Western area of the Black Sea basin. The sea currents are important not only for the perpetuation of the marine life, but also the knowledge of the general current patterns can reduce considerably the shipping costs. Knowledge of the current patterns, velocities and orientation is also important in the unfortunate case of marine accidents.

In general, the current speed values for the Black Sea are small. There are some points where the maximum speed can reach $1ms^{-1}$ and even $2ms^{-1}$ during the storms, but these are in general isolated cases. The North-Western sector of the Black Sea, which was particularly considered in the present work, does not appear to make exception from the general case. The current velocity values presented here are in concordance with those analyzed for other areas of the Black Sea basin, the maximum current velocity being between $0.29ms^{-1}$ and $0.57ms^{-1}$. Regarding the current direction, the present work supports the general theory presented by Titov *et al.* (2008), stating that the still weather and the missing strong wind may cause current instability for the summer period.

6. ACKNOWLEDGMENT

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REFERENCES

[1]. **Blokhina M. D., Afanasyev Y. D.,** 2003, Baroclinic instability and transient features of mesoscale surface circulation in the Black Sea: Laboratory experiment, Journal of Geophysical Research, 108, pp. 20-31 (12).

[2]. **Enriquez Ortiz C. E.,** 2005, Mesoscale Circulation in the Black Sea: A Study Combining Numerical Modelling and Observations, PhD Thesis, School of Earth, Ocean and Environmental Sciences, 257 pp

[3]. **Mee L, Maiboroda O.,** 2006, Black Sea Study Pack: A Resource for Teachers, Black Sea Ecosystem Recovery Project, 87 pp.

[4]. **Rusu E., 2009**, Wave energy assessments in the Black Sea, Journal of Marine Science and Technology 14 (3), pp. 359-372 (24), Rusu E., 2010a. Modelling of wave-current interactions at the mouths of the Danube, Journal of Marine Science and Technology 15 (2), pp. 143-159 (17)

[5]. **Rusu L., Ivan A.,** 2010, Modelling wind waves in the Romanian coastal environment, *Environmental Engineering and Management Journal*, 9 (4), pp. 547-552 (6).

[6]. **Toderascu R., Rusu E.,** 2012b. Implementation of a global circulation modeling system for the Black Sea basin, 12-th International Multidisciplinary Scientific GeoConference SGEM 2012, 3, pp. 739-746 (8).

[7]. **Toderascu R., Rusu L.,** 2012,a Study on the currents variability and patterns in the Black Sea, 12-th International Multidisciplinary Scientific GeoConference SGEM 2012, 3, pp. 825-832 (8)

[8]. **Titov V.B., Savin M. T.,** 2008, Spatial structure of the Black Sea current field, Russian Meteorologiya i Gidrologiya, Russia, pp. 80-92 (13).