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CHARACTERISTICS OF THE ENVIRONMENTAL MATRIX IN THE ROMANIAN BLACK SEA AREA

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ABSTRACT

The paper aims to present the main features of the environmental matrix in the Black Sea, whose trends and variability are extremely important issues for a wide range of marine activities. Therefore, the knowledge of wave and wind climate is vital for coastal infrastructure, including ports design, erosion and shoreline protection, sediment transport, etc. The paper summarizes the observations obtained from the meteorological stations Sulina, Constanta and Mangalia, as well as the satellite data regarding the wind regime, taking into account their frequency and speed on the cardinal points direction, and the frequency, intensity and duration of the storms. The study shows that winds regime is characterized by a wide variability both in direction and speed, and the storms on the Romanian coast of the Black Sea occur especially in the cold season. The paper also presents data regarding the waves regime considering the direction of the waves, their height and period. The waves along the Romanian Black Sea coast are produced mainly by the wind, whereas the swell rarely appears. As a result, the regime of the waves is influenced by the winds. The dominant waves direction from the distance is north up to the east.

Keywords: hydro-meteorological conditions, storms, conditions of the sea, wind speed and direction.

1. INTRODUCTION

The Black Sea is a continental sea, semi-closed with dimensions relatively small (432,000 km2 surface and 538 124 km3 volume), situated between the South-eastern Europe and Asia Minor that bathes the shores of Romania (over a length of 245 km), Ukraine, Turkey, Bulgaria, Georgia and Russia. The Black Sea communicates with the planetary ocean and with the Mediterranean Sea through the Bosporus Marmara Sea- Dardanelles straits system and through Kerch Strait with the Sea of Azov. It has broadly oval form and slightly jagged shores (except for the Crimean peninsula) and in the northwest it has numerous estuaries. The Continental Shelf is very extensive, especially in the northwest, then the depths increase, reaching in the south-central region 2,425 m. The average annual temperature in the Romanian sector is +12.50 degrees, exceeding by 20 degrees the average temperature of the air. In winter, the temperatures drop enough, the northwest winds frequently blow, causing large waves very dangerous for navigation. In colder winters, in the northern littoral zone the Black Sea freezes. Under the influence of the winds, a circular current is formed, along the shores line, which, due to the Crimean peninsula, is divided into two closed branches: eastern and western [2]. Knowing the main features of the environment matrix in the Black Sea, the trends and their variability are very important issues for a

wide range of marine activities, including designing in economic and safety conditions, the operation of the oil and gas platforms, the ship design, the strategic planning for marine towing operations. Therefore, the knowledge of the wave and currents climate is vital to design the coastal infrastructure, including the ports design, the erosion and protection shoreline, the sediment transport, etc. [19].

2. WIND REGIME

The wind is the air movement relative to the Earth's surface and is defined by two elements: the direction and the speed of air masses. The cause of the movement of air masses consists in the uneven distribution of the atmospheric pressure in space. Thus, the wind arises under the baric gradient action. The space above the Black Sea is under the influence of the baric gradients generated by the Euro-Asian anticyclone and the Mediterranean cyclone. In all seasons, the cyclone from the eastern part of the sea is also present and is formed due to the influence of relief, especially of the Caucasian mountains on the air masses circulation from this region. The cyclone has a frequency of 9-10%. The formation of sea breezes is specific to the coastal area. They arise due to the contrasts of temperature between sea and land area. Their activity is highest during the warm season of the year.

2.1. Wind direction and speed in the closed area of the Romanian seaside

To establish the periods of the year with the highest risk in terms of hydro-meteorological significant statistical values, the meteorological observations regarding the wind direction and speed recorded at the meteorological stations placed in Sulina, Constanta and Mangalia are required. The multiannual and monthly averages provide a general representation of the existing hydro-meteorological conditions in the Black Sea, at the Romanian seaside. The wind frequency on the cardinal points direction differs from one region to another [1].

Ehe examination of data on wind frequency at two stations on the Black Sea (Constanta and Mangalia) between 1965-2000, revealed that the winds with the biggest frequency were from the western direction, with a share of 17% in Constanta and 20.3% in Mangalia [1]. They are felt especially in the cold season. Near the shoreline, the data obtained by the Antipa Marine Research Institute in the period 1971-1994 on the coastal environment near the Constanta port, points out that the wind that comes from the northern sector (NV, N and NE) is dominant, accounting for about 40. 3% of the annual total, while the wind coming from the south is 33.8% [12]. For the period 1998-2007, the seasonal change of the wind direction at three meteorological stations (Constanta, Sulina, Gloria) is illustrated in the following charts (Fig.1a - Fig. 1 l). The average monthly frequency is given in %, and is calculated for the study period 1998-2007 [6].

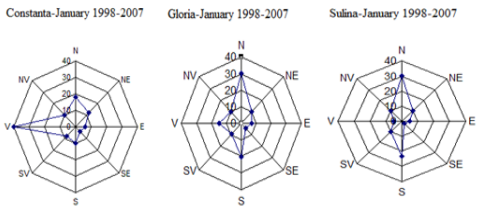

Fig. 1 a The average monthly frequency of the wind (%) January (1998-2007) [6]

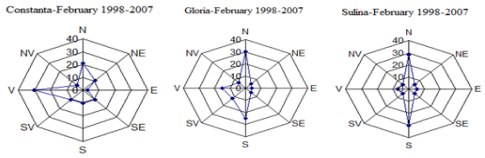

Fig. 1 b The average monthly frequency of the wind (%) February (1998-2007) [6]

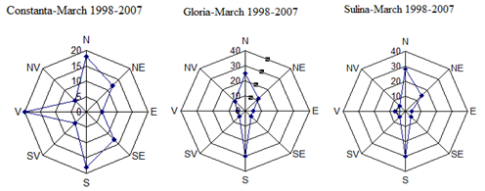

Fig. 1 c The average monthly frequency of the wind (%) March (1998-2007) [6]

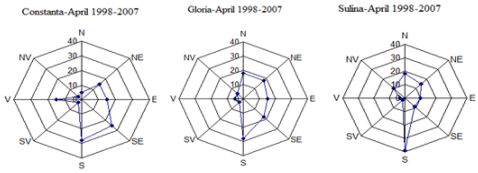

Fig. 1 d The average monthly frequency of the wind (%) April (1998-2007) [6]

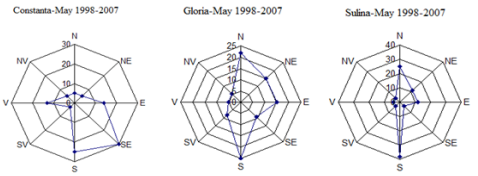

Fig. 1 e The average monthly frequency of the wind (%) May (1998-2007) [6]

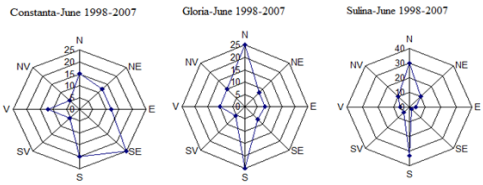

Fig. 1 f The average monthly frequency of the wind (%) June (1998-2007) [6]

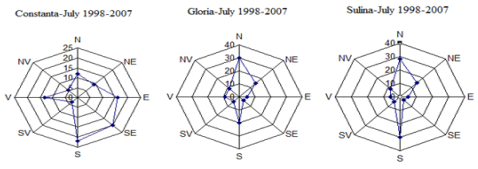

Fig. 1 g The average monthly frequency of the wind (%) July (1998-2007) [6]

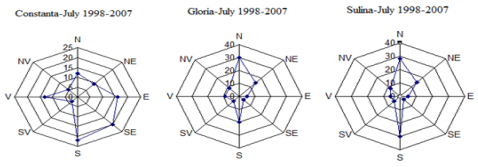

Fig. 1 h The average monthly frequency of the wind (%) August (1998-2007) [6]

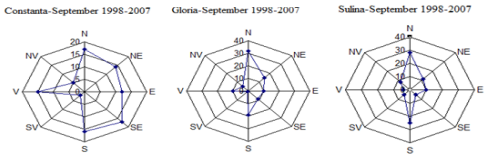

Fig. 1 i The average monthly frequency of the wind (%) September (1998-2007) [6]

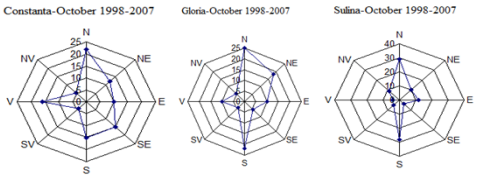

Fig. 1 j The average monthly frequency of the wind (%) October (1998-2007) [6]

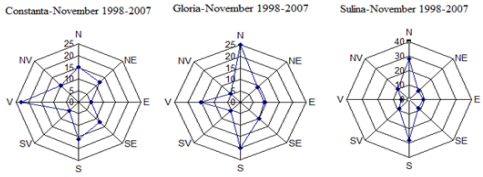

Fig. 1 k The average monthly frequency of the wind (%) November (1998-2007) [6]

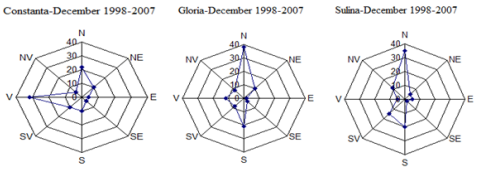

Fig. 1 l The average monthly frequency of the wind (%) December (1998-2007) [6]

From the analysis of the representations of the submitted data regarding the average frequency of the wind on directions, the following characteristics can be distinguished for each month of the year:

In January, the winds from the north have the highest frequency at Gloria and Sulina stations, which are located in the coastal zone.

At Constanta station the maximum frequency can be noticed for the west winds.

In February, the situation of the frequency distribution is similar to January.

In March changes occur regarding the frequency distribution in terms of directions versus January and February, as the south winds are more frequent at Gloria and Sulina stations. The south winds exceed the north winds in terms of frequency at Gloria station.

In April, the winds from the south prevail at all stations near the shore area.

The frequency of the wind on directions presents similarities between June and July.

At Gloria and Sulina stations, the prevailing winds are from the north and south. Starting with September and throughout the cold season there is an increase in the frequency of winds from the north. High frequencies of the winds from the south are also recorded in October and November at Gloria and Sulina, related to the moving of the Mediterranean cyclones over the western basin of the Black Sea.

The predominance of the winds from the north is the result of the winter atmospheric circulation, characterized by the presence of the continental anticyclones (north or northeast Europeans, Asians) and the intensification of the winds at their periphery.

From the data examined it results that the west and northwest of the Black Sea, in the immediate area of the coast, are throughout the most part of the year under the influence of the winds from north and west. They are dominant in the cold season.

In the hot season, from April, starting with the restructuring of the baric field, the prevailing winds are from south, southeast and east.

It is important to have knowledge regarding the wind speed, because it is the main factor that determines the degree of agitation of the sea, respectively the periods of storm. An increased wind speed increases the risk of marine accidents [20].

Between 1965-2000, the records from Constanta and Mangalia stations showed that the highest speed is recorded on the north direction at Constanta (6.5m/s) and northeast at Mangalia (5.6m/s). They occur mostly in the cold season and predominantly in January. The winds with the lowest speed (3.4m/s) are those manifested on the southwest direction for the coast stations [19].

Another study [7] based on the meteorological observations from the 1961-2000 period at the meteorological stations placed at Sulina, Constanta and Mangalia shows, according to the seasons, the multiannual averages of the wind speed and frequency on its direction of propagation (Figure 2).

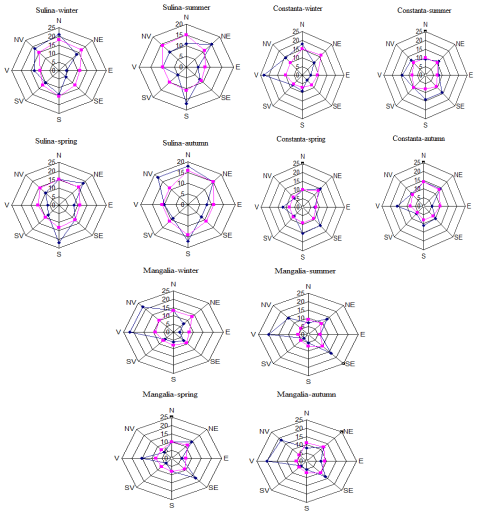

Fig. 2 Average multiannual values (for every season) for frequency (%) and the mean speed of wind (Nd) at Sulina, Constanta and Mangalia. The frequency is represented by the blue line, and the speed by the pink line [7]

Based on the analysis of the graphs above, the following conclusions can be drawn:

- in winter, the highest wind frequencies are recorded in the north-west and west-northwest sectors. For these prevailing sectors, the wind average speed is about 15 Nd (Nd = 1 mM/h). The highest wind speed is recorded in Sulina, but the maximums of the medium speed are 16-18 Nd, on the north and northwest directions;
- during spring, the wind is predominant in the south and south-eastern sectors and the average wind speed drops to about 11 Nd. The strongest winds are recorded in Sulina, with average speeds of 15 Nd, both from the north and south sectors;
`-in summer, the average of the wind direction frequency is from the north and west sectors, the average speeds being below 10 Nd. In terms of wind direction, in Sulina the situation is similar to the spring season, wind speed registering a significant decrease.

For Constanta and Mangalia areas, the prevailing wind is from the southeast sector with speeds not exceeding 8 Nd;
- in autumn, a return of the predominant wind from the northwest and west sectors is recorded, the wind speed increases to an average of about 12 Nd, with peaks of 14-16 Nd on the north and south directions, especially in Sulina.

By presenting the average multiannual values of the wind speed, their extreme values are attenuated.

The maximum value of the average annual value for the wind speed is 5.6 m/s from northeast in Mangalia, of 6.4 m/s from north and northeast in Constanta and 8.1 m/s from north in Sulina. These maximum values are recorded in December, while the minimum average values are recorded in August at Sulina and Constanta stations and in July at Mangalia station.

The variation of the average wind speed during the year is due to different baric configurations in the cold season compared to the warm season, and the variation from one station to another is determined by the geographical latitude and the various forms of relief.

Another study conducted in 2007 showed the following observations [22].

The prevailing wind direction in Constanta is northwest till northeast and the winds from south and southeast are well represented, with lower speeds.

The winds from east or west are rare. The average annual wind speed is 3.8 m s, the calm status (wind speeds less than 0.5 m/s) being 13.7%. The strongest winds are in January, with an average speed of 4.5 m/s, with a calm of 8.3%, while the worst are in August, with the average speed of 3 m/s and a calm of 19.5%. The wind speed exceeding 10% is of 8.7 m/s, and for those exceeding 1% is of 13.7 m/s [21].

The strong winds over 14 m/s are distributed in proportion of 60% on the north and northeast directions and those with higher speed of 23 m/s correspond almost exclusively to the north and northeast directions and they are characteristic to the storms with the highest frequency on the seaside [15].

It is considered that the frequency of the strong storms is one in about 70 years.

2.2. Wind speed for the entire sea

The wind speed presents variations based on the distance from the shore. Compared to coastal meteorological stations, the average values on the Gloria Platform are higher by 3-4 m/s in the cold season and by 2-3 m/s in the warm season. The maximum wind speeds may exceed 35-40 m/s over the continental shelf of the Black Sea [9].

The measurements carried out daily for a three-year period between 2002 and 2004, to an interval of six hours at the Gloria drilling platform which is located in the west part of the Black Sea (44031'N, 29034'E) showed that the wind dominant direction was from north, northeast, and south-southwest, and the wind speed was higher than 8-10 m/s at a rate of about 9% and over 10 m/s at a rate of 12% for the whole year, and over 15% during winter.

An overview regarding the location in the Black Sea basin of the most relevant points in terms of higher average values of the main environmental parameters (significant wave height, wind speed, current speed and the sea level) is shown in Fig. 3 [19].

The satellite data showed that in the points B1, B2, B3 (Figure 3) there were prevailing winds with speeds of 0 ... 4m / s, and in other points there were prevailing winds with higher speeds.

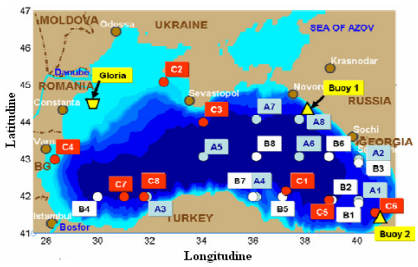

Fig. 3 The location of the references points taken into consideration for the analysis of the environmental parameters in the Black Sea. A-significant wave height; B-wind speed; C-current velocity and sea levels [19]

At the Black Sea level, the average wind speed varies [11]: Sulina 7.1 /s; Mangalia 4.5 m s; Constanta 5.1 m/s; in off-shore over 9 m/s; Dobrogea Plateau (10 m above ground) 2.8 ... 4.4 m / s.

The wind speed on the entire sea reaches the highest monthly average values in the cold season (October-March) of 5.02-6.19 m/s and the minimum values in the rest of the year of 2.77-4.0 m/s.

In conclusion, there is a considerable variation of winds recorded for both direction and speed, without regular winds over the Black Sea coast or in its west part.

2.3. Storms

The wind main feature, used in literature to define the storms in the Black Sea, is the wind speed. The limit values for this parameter used by various authors to characterize the storms are 10 m/s [11], 12 m/s and 14 m/s [8].

The strong winds represent a risk factor for navigation not only because of their intensity but also in terms of duration.

Regarding the storms of the western basin of the Black Sea and their impact on navigation, the limit values for the wind speed are established at 12 m/s at least for 12 consecutive hours, in at least one of the Romanian coastal stations: Constanta, Sulina and Mangalia [8].

For a period of 10 years (1998-2007), based on the data provided by the coastal meteorological stations Constanta, Sulina and Gloria, the average number of days for the wind duration with speeds of 10 m/s, 12 m/s and 14 m/s has been calculated (Fig. 4) [6].

Figure 4 shows that the strong winds prevail at all stations during the cold season, from September to March, but the average number of days with wind speeds over 12 m/s significantly increases toward the shore, the maximum values being reached at Gloria station. The winds with speeds exceeding 14 m/s were recorded, notably, in December at Constanta and Gloria stations and in January in Sulina, the maximum number of days being recorded at Gloria station.

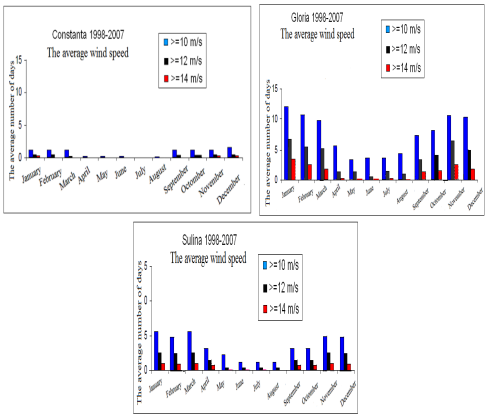

Fig. 4 The average number of days (1998-2007) of the wind duration with speeds above 10 m/s, 12 m/s and 14 m/s [6]

The storms lasting over 12 hours had an annual average of 29, there were 12 storms which lasted 24 hours and 4 storms of 48 hours [14]. In the vast majority (75.1%), the storms recorded in the central area of the Romanian transition seaside are due to the winds from the northern sector (N and NE), those from east and southeast with a frequency of only 5%.

At the Romanian coast of the Black Sea, the necessary conditions for triggering storms are created especially in the cold season, when over the warmer waters of the sea prevail the depressionary baric fields, with unstable air stratification and extremely high horizontal gradient of the wind speed. This situation determines, along with the penetration of ultrapolar air from northeast, the strongest storms of the season. The number of days with storm on the western shore of the Black Sea can vary from 20 to 40 days a year, most of the days being in winter [16].

The detailed analysis of the statistical distribution of the storms duration, using classes of 12 hours, highlighted that 58.3% of the events had 12-24 hours, 18.7% had 24-36 hours, and only 2.7% lasted more than 72 h [14].

The achieved studies on the causes of the storms showed that between 1974-1993, 50% of them were due to the interaction between a continental anticyclone and a depression of Mediterranean origin extended above the Black Sea [8].

3. WAVES REGIME

The waves represent the most important factor in the evolution of the coastal zone. The main cause of the wave formation is represented by the movements of air masses, which transfer their energy to the water, forming the waves. For the wave formation the size of the water surface over which the air masses have constant features (fetch) is also important [4].

At the Romanian shore of the Black Sea the wave regime is characterized by high inconstancy of their direction, height and period.

The waves along the Romanian Black Sea coast are specially produced by winds, the swell occurring rarely. As such, the regime of waves is influenced by winds. The predominant wave direction from the distance is from north to east, but it is transformed in the north-east sector till east, as a result of wave refraction effect. However, there are some waves coming from south [3].

INCDM data regarding the wave height and their direction shows a predominance of the waves with east direction (27.66%), followed by those with northeast (17.61%) and east-northeast direction (16.95%), and a wave height of 0.5-1.0 m (40.25 %), a wave height of 0-0.5 m (27.27%) and a wave height of 1-1.5 m (17.57%) [14].

The stepping sea commotion occurs in October and November when the calm frequency and the sea of grade 1 decrease to 30-40% and the characteristic sea waves of grade 2 and 3 are predominant. In the Romanian seaside area with depths below 40 m, the waves development time is reduced and falls in the range of 20-200 minutes, depending on the wind speed.

The silence and wave extinction time lasts between 2-5 hours. The wind waves are more numerous (approx. 80%) than swell (approx. 20%) and their diminishing or extinguishing is realized in the situations of prolonged atmospheric calm or when the wind starts to blow in the opposite direction to their propagation [17].

The wave propagation directions are determined mainly by the wind direction, but the shoreline configuration also counts. In general, the winds from east, southeast, south, southwest sectors, "mounted" the sea along the entire Romanian coastline; the winds from west fail to agitate marine waters at some distance from the shore.

The wave propagation frequency does not correspond to the wind frequency. Thus, for a wind frequency from a distance (northeast, east, southeast) of 44.5%, the waves frequency is almost double (86.4%); the situation is reversed for the landward winds (southwest, west, northwest) with a higher frequency (33.3%) than of the waves (8.7%) [18].

In spring, the calm frequency and the sea of grade 1 increase up to 50-60%. The direction of wave propagation in this season is unstable. In summer, there is a continuous weakening of the waves when the sea of 6 degrees frequency does not exceed, on average, 2%. The strong waves are formed from the west till the north and the waves under 1m are predominant.

In the western part of the Black Sea, the strong waves are observed especially in the cold season. The frequency of the sea of grade 6 and over may reach 10%, while the direction of wave propagation is from northeast and north, and the wave height can reach 7 m [5].

In terms of waves that are generated by the wind, the most important aspect of their development is the relation between wind speed and wave size. In general, with the increasing of the wind velocity, the size of the waves will also increase and conversely.

The changes of the waves height occur

with some delay according to the fluctuation of the wind speed.

The increase of the waves height does not take place only due to the wind intensification. It also occurs even for constant wind speeds, having the same direction for longer period (example: during 6 hours at a wind speed of 9 m/s , the waves height increased from 0.9 m to 1.2 m, and their length from 15 to 28 m).

The highest waves are produced by winds blowing from northeast. These waves, especially in winter, can exceed 3.5 m height at a wind speed of 30-40 m/s. The waves caused by winds from the eastern and southern sectors are smaller, 3 and 1 m height respectively [10].

The dominant winds from the northern sector are reflected in the fact that most of the wind waves (15.5%) are spread from northeast (41.2% from northeast, east-north-east and east), while the effect of refraction makes that 16.2% of the swells come from the east (31.1% with adjacent directions). Moreover, on the normal direction to the coast - east - the highest average of the wave elements is recorded: 1.2 m in height, 2.5 s period and 34 m in length.

The maximum wave height measured in 24 years (1971-1994) in Constanta area was 6.0 m [12].

In the southern area of the Romanian Black Sea coast (from Midia to Vama Veche) the annual average of the significant wave height is 0.95 m, with a period of 5.1 s. The most powerful waves are in December and January, with the average of the significant wave heights of 1.2 m and 5.3 s period. In June and July the mean values of the wave parameters are the lowest, with the average of the significant wave height of 0.67 m and 4.5 s period.

The extreme waves, with the return period of 10 years and 100 years, are estimated as having significant height of 6.5 m and 7.8 m, with periods of 10.2 s. As they approach the shore, their heights are limited by the water depth, as a result of breaking waves. For example, at a depth of 5 m, the secular waves will have the significant wave height of only 3.5 m [13].

The average monthly values of the significant wave height are the biggest in the cold season, in the period October - March, respectively (0.72-1.42 m) and the lowest values in the warm season (0.54-0.69 m) [19].

4. CONCLUSIONS

- In most part of the year, along the Romanian coast, the sea is subjected to the action of winds which produce waves. Of all these, about 80% are wind waves and only 20% are swell waves.
- Above the Black Sea basin, the baric field has a seasonal variation, which causes the seasonal change of the wind direction. The west and northwest part of the Black Sea, in the immediate coast area, is under the influence of winds from north and west during the most part of the year. They are dominant in the cold season. In the hot season, from April, with the restructuring of the baric field, the winds from south, southeast and east are dominant. The biggest speeds of the wind are reached in the cold season, the maximum average values being in December, 5.6 m/s at Mangalia station from northeast, 6.4 m/s at Constanta station from north and northeast and 8.1 m/s at Sulina station from north and the minimum average values are recorded in August in Constanta (under 4 m/s) and Sulina (5.3 m/s) and in July in Mangalia (under 4 m/s).
- For the entire sea, according to the data from the satellite for the environmental parameters, the mean monthly values of the wind speeds are the highest during the cold season (October-March) of 5.02-6.09 m/s, and the lowest values are in the warm seasons with values of 2.77-4.0 m s.
- Regarding the storms, taking into account the limit values for the wind speed of 12 m/s, they are dominant in winter (October-March), and the average number of days that records wind speeds over 12 m/s significantly increases

at shore line, where there are winds from the northern sector (N and NE).

- The propagation wave directions are mainly determined by the wind direction and the configuration of the shore line. For the area along the Romanian coast, the dominant wave direction from the distance is from north to east, but there are waves in the south direction, too.
- The bustle of the sea increases in October and November and decreases in spring and summer when the frequency of the calm and the sea of the first grade increase.
- The average values of the wave parameters are the highest in December and January (significant height 1.2 m and the period 5.3 s) and the lowest in June and July (significant height 0.67 m and the period 4.5 s), the annual average of these parameters being 0.95 m for the significant height and 5.1 s for the period.

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