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ANALYSIS OF THE EXTREME ENVIRONMENTAL CONDITIONS IN THE BLACK SEA CONSIDERING DIFFERENT DATA SOURCES

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ABSTRACT

The main objective of the proposed work is to provide an extensive and a more comprehensive picture of wind and wave conditions in the Black Sea basin. The emphasis is put on the analysis of the wind measurement. This is based on 17 years of data (1994–2011,) coming from eleven meteorological stations located in the northern part of the Black Sea. Furthermore, twenty-one data points contain information synchronously coming from seven satellites. These are close to actual time multi-mission interflowed no inserted values of the environmental parameters (waves, currents, wind and sea level).

Keywords: Black Sea, extreme conditions, wind, waves, different data

1. INTRODUCTION

The Black Sea is a ringed sea, located deeply inner the continent that constitutes the most isolated part of the World Ocean. In the south-west, it is linked to the Sea of Marmara via the Bosphorus Strait; the frontier between the seas passes along the line Cape Rumeli-Cape Anadolu. The Kerch Strait joins the Black Sea and the Sea of Azov. The maximal length of the sea along the latitude 42°29' N is 1148 km, while its minimum width along the meridian, from Crimea to the coast of Turkey, is only 258 km [1]. The main characteristics of the Black Sea are: 423000 km^2 for the sea area, 555000 km^3 for its volume and 1315 m and 2258 m for the mean and maximum depths, accordingly [1]. The length of the coastline reaches 4125 km; of this, the length of the Bulgarian, Romanian, Ukrainian, Russian, Georgian and Turkish coast equal 380 km, 240 km, 1330 km, 410 km, 315 km and 1450 km, respectively[1].

The Black Sea is one of the most active regions in the world. It is considered a significant economic and geopolitical background. It is famous for the ship courses, which unite Europe to Asia. Concerning the natural conditions, it can be adverted that antecedent studies reported more firm wind and wave characteristics in the western part of the sea, acceptable for some sites to report incidents or extreme events, such as in the case of the Danube River mouths or in the north-eastern part of the sea, more exactly in close vicinity to the Novorossiysk region, where the Bora wind takes place [2]. In the open sea areas, the safety of a ship is directly linked to the extreme conditions faced all along the navigation itinerary, reporting more concordant dates during more dynamic winter-tide. Usually, at oceanic sites easily happens such events when large ships may overturn. Nevertheless, these incidents could be faced as well in the enclosed sea areas. The Black Sea is not an exception. In this region, extreme events cannot be disparaged. Powerful storms often occur in the Black Sea, when the wave conditions are likening with those from the ocean areas [3]. In the Black Sea, there are also some regions, as for example, the entrance to the Sulina channel (Romania), that are exposed to high navigation traffic and where intricate phenomena (in this case, wave-current interactions) make the process of wave prediction even more complicated [3]. From this point of view, a precise prediction of such situations is of exceptional importance for averting sea and coastal hazards that may have very high economic and ecological outcomes.

Therefore, a more precise evaluation of the extreme conditions and of the most expected storm designs represents an issue of growing importance. In these bonds, the objective of the present work is to identify tendency and design regarding the most significant extreme environmental conditions in the Black Sea. In order to do this, a 17-year wind measurement and wave hindcast (covering the time interval 1994–2011) will be analyzed, based on the results from different data sources, both satellite measurements and datasets coming from numerical models [3,4].

2. METHODS AND MATERIALS

In general, the low coastline is one of the main characteristics of the west and northwest areas. The major reference point of the basin is the Crimean Peninsula. The Black Sea is mostly ringed by mountains, with the Crimean Mountains in the north and the Pontic Mountains and the Great and Lesser Caucasus dominating the south and east sides of the Sea [6]. In the western area, a plateau region is facing the Danube Delta, which is the most important component in that region. The sea basin is overloaded by the presence of gulfs with the Sinop and Samsun in the south, while the Kalamitskii, Varna and Burgas are the most important in the north-west and west sides [6].

By reason of its geographical location, the Black Sea climate is affected by continental, polar and marine tropical air masses coming from different directions. The marine tropical masses of air take place due to the southwest winds from the Mediterranean basin when, during the winter time, the existence of polar air masses from the north and north-east run too low temperatures and frequent storms in the basin [6].

Preceding studies of the wind conditions show the western part of the analyzed region to be more active and dynamic, with a mean wind speed of 5 ms^{-1} for the summer and approximately 8 ms^{-1} for the winter. It is considered, however, that the wind conditions in the western part of the sea record high seasonal alterations and the eastern area are described by more sustained conditions [16]. In the winter, ruthless storm conditions appear mostly in the western area, under the influence of the east and north-east winds. During a storm, wind speed can easily exceed 40 ms^{-1} in the open sea and 25 ms^{-1} in the nearshore area [6].

Two distinct data sources have been considered in the present work. These are measured wind data provided by weather stations located near the northern coast of the Black Sea and satellite observations.

3. RESULTS AND DISCUSSIONS

The map of the Black Sea is presented in Figure 1.

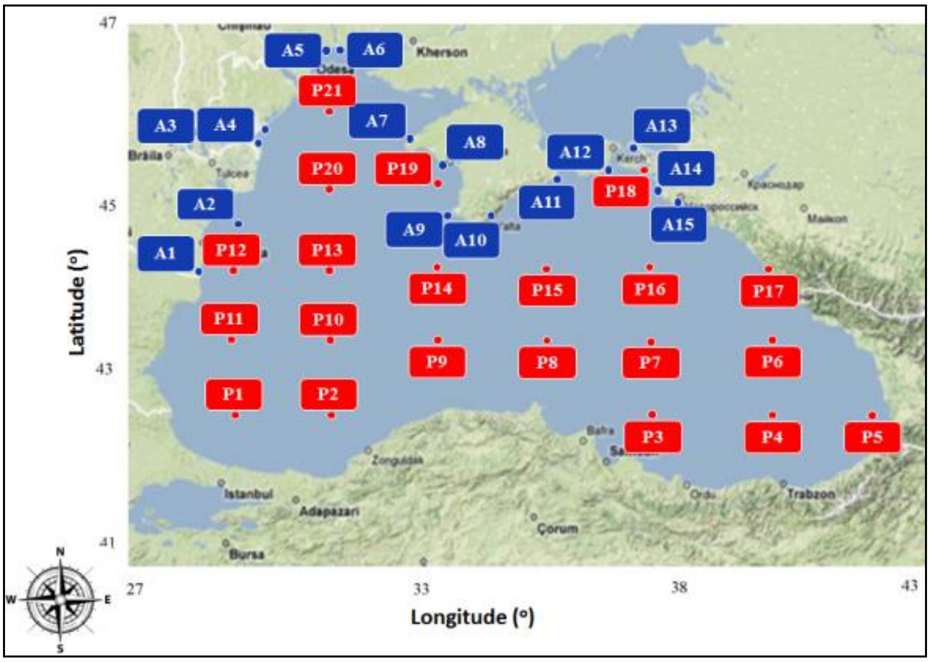

Fig. 1. Map of the Black Sea, illustrating the locations of the studied sites (11 meteorological stations, denoted as A points and 21 reference points, considered in the analyses of the satellite and model data, denoted as P points). Figure processed from Google Earth (2016).

For this study, in the northern area the locations of the study sites were illustrated as A1-A15, for which the wind and wave conditions will be estimated. The first two stations, A1 and A2, provide sample wind dates for the Romanian nearshore. A1 weather station (WS) is located near Mangalia harbor and operates at 8 m water depth with data. A2 operates at sea, on the Gloria platform, at about 50 m water depth. Provided data are available for a 7 year period, from January 2003 to December 2009 [6]. For A1, the measurements are received at 10 m above the mean sea level and for A2, at 36 m.

Other thirteen studied weather stations (A3–A15) are representative of the Ukrainian (A3–A12) and Russian (A13–A15) coastal areas. Wind dates recorded at 10 m above the mean sea level are accessible at these stations for a 15 year period (from January 1994 to December 2009). In Table 1, more detailed information about these weather stations is described.

Table 1. The positions and the main features of the meteorological stations considered.

Station number	Station name	Latitude (N)	Longitude (E)	Type of station	Wind measured	Number of measurements per day	Time interval
A1	Mangalia	43° 48′	28° 53′	HMS	U10	4	2003–2009
A2	Gloria	44° 31′	29° 34′	HMS	U36	4	2003–2009
A3	Ust-Dunaysk	45° 29′	29° 43′	HMS	U10	4	1999–2009
A4	Primorskoye	45° 31′	29° 37′	HMP	U10	2	1999–2009
A5	Yuzniy	46° 36′	31° 01′	HMS	U10	4	1999–2009
A6	Ochakov	46° 37′	31° 32′	HMS	U10	2	1999–2009
A7	Chernomorskoye	45° 31′	32° 42′	HMS	U10	4	1999–2009
A8	Evpatoriya	45° 11′	33° 22′	HMS	U10	4	1999–2009
A9	Khersoneski Mayak	44° 35′	33° 23′	HMS	U10	3	1999–2009
A10	Ialta	44° 30′	34° 10′	HMS	U10	4	1995-2005
A11	Feodosiya	45° 02′	35° 23′	HMS	U10	4	1999–2009
A12	Zavetnoye	45° 08′	36° 25′	HMP	U10	2	1999–2009
A13	Tamani	45°12′	36°42′	HMS	U10	4	1999-2009
A14	Anapa	44°53′	37°19′	HMS	U10	4	1994-2004
A15	Novorossiysk	44°43′	37°46′	HMS	U10	4	1994-2004

Note: HMP, Hydro Meteorological Post; HMS, Hydro Meteorological Station.

Many of these stations are located close to the coastline, not more than 4 km offshore, with the exception of Gloria, which operates at 30 km eastward from Portita Inlet. Based on the fact that the wind speed increases with the distance from the shoreline, it is more than possible, in this location that higher wind magnitude will be recorded.

Some statistical information for the data jot down at the A points are shown in Table 2. The research data are structured in total and winter time, respectively (the winter is considered the period from 1 October to 31 March). The evaluated statistical parameters are 50th and 95th percentiles, standard deviation, skewness and kurtosis [6].

In Table 2, the analysis of the 50th percentiles shows that A2 is the most dynamic location, 8 ms^{-1} during winter and 7 ms^{-1} during the total time. Regarding others stations, A3 is more energetic, with a value of 5 ms^{-1} in total and winter time and A5 and A9, with a value of 5 ms^{-1} only in winter time. The least energetic location could be considered A10, because of its value approximates 2 ms^{-1} for winter and total time. For the 95th percentile, the most energetic point is also at A2, with a value of 14 ms^{-1} in winter time, A3 goes after, with 12 ms^{-1} for both total and winter time. Lowest wind speed conditions were registered at points A10 and A6, where the value is 7 ms^{-1} (total time and winter).

The most frequent case of the wind speed by the mode (presented in Table 2) is at the A2 point, where the maximum value is 8 ms^{-1} during the winter. The skewness index is positive for all points, with values between 0.29 and 1.69. The kurtosis index has higher values in A1 and A11, with a value more than 7 (total time and winter), while the lowest indicator is in A9 (2.89 in winter).

Because of the insufficiency of the extended network of adequate observations in the Black Sea, it can be also gathered additionally satellite data that can provide wind supervisions over the entire sea, with a valuable spatial and time reach.

Table 2. Wind statistics for the meteorological stations located in the northern sector of the Black Sea (A-points).

Station number	Time period	Number of obs.	50th (ms^{-1})	95th (ms^{-1})	Mode (ms^{-1})	Std. (ms^{-1})	Skew	Kurt	%	
									< 3 ms^{-1}	3–20.2 ms^{-1}
A1	Total	10 228	3	8	2	2.19	1.65	7.70	45.00	54.97
	Winter	5250	3	8	2	2.42	1.69	7.51	42.62	57.35
A2	Total	10 228	7	13	5	3.40	0.35	3.10	11.29	88.63
	Winter	5250	8	14	8	3.46	0.29	3.28	6.80	93.04
A3	Total	17 528	5	12	3	3.30	0.83	3.58	18.91	81.07
	Winter	7986	5	12	3	3.52	0.77	3.35	18.09	81.88
A4	Total	8764	3	10	3	2.65	1.28	5.35	29.24	70.75
	Winter	4026	3	10	3	2.77	1.32	5.39	27.94	72.05
A5	Total	17 523	4	9	3	2.63	0.74	3.65	22.42	77.56
	Winter	7986	5	10	3	2.75	0.71	3.70	18.40	81.58
A6	Total	8764	3	7	2	2.20	1.39	5.70	45.17	54.82
	Winter	4026	3	9	2	2.41	1.37	5.47	40.26	59.73
A7	Total	17 524	4	10	2	2.82	0.84	3.58	30.11	69.87
	Winter	7986	4	10	2	3.00	0.70	3.27	25.05	74.93
A8	Total	17 527	4	9	2	2.61	1.31	5.39	30.27	69.72
	Winter	7986	4	10	3	2.87	1.19	4.76	27.04	72.95
A9	Total	14 300	4	10	2	2.81	0.78	3.24	28.68	71.31
	Winter	6006	5	11	2	3.05	0.59	2.89	22.31	77.68
A10	Total	17 527	2	7	2	1.95	1.26	5.30	56.80	43.19
	Winter	7986	2	7	2	2.15	1.15	4.45	52.98	47.01
A11	Total	8755	3	8	2	2.39	1.62	7.42	45.37	54.62
	Winter	4026	3	8	2	2.54	1.58	7.23	39.69	60.30

The primary source of satellite data, reflected on the present work, comes from the AVISO website (www.aviso.oceanobs.com) and for this reason, the present analysis includes the interval December 2006 to March 2014, when data are available [6].

The wind conditions data available represent daily wind speed values corresponding to a grid network (1°× 1°) placed over the Black Sea area [6]. Twenty-one reference points were selected and denoted as P points. Their positions are displayed in Figure 1, from P1 to P21, and cover the entire basin. Figure 2 presents the progress of the mean wind speed values for all 21 points, both in total and winter time. Based on these results, the P points located on the western side of the Black Sea appear to have more energetic wind conditions (in both winter and the total time).

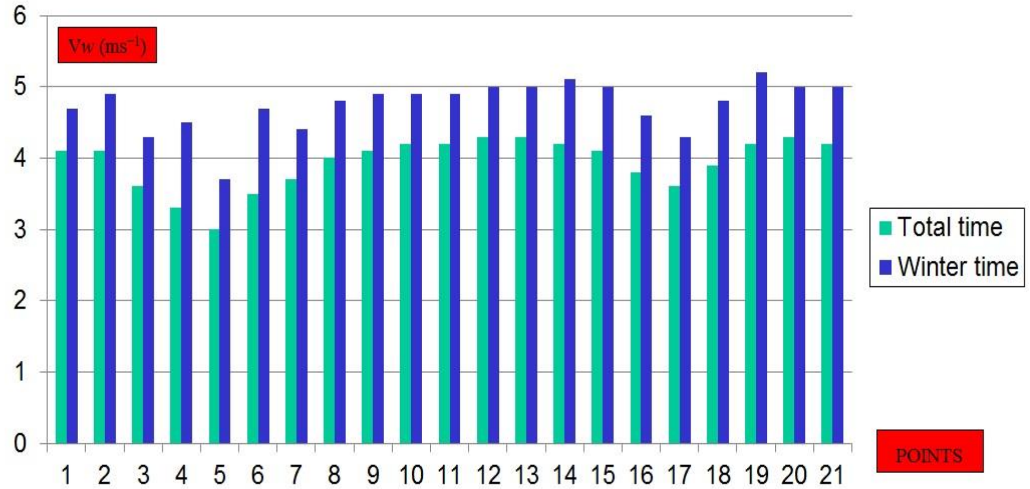

Fig. 2. Distribution of the median wind speed conditions, as reflected by the satellite data. Analysis performed for the 21 P points (total time and winter), considering the interval December 2006 to March 2011.

During winter time, the highest wind conditions appear at P19, with value 5.2 ms^{-1}. The lowest wind speed is manifested at P5 (3.7 ms^{-1}). For the total time, the most energetic location occurs at P 20. For the rest of the reference points, wind conditions are in the range of 3.6–3.8 ms^{-1}.

In order to estimate the thorough distribution of the wind conditions over the Black Sea basin, five reference points from the western area of sea (P2, P7, P13, P14 and P20) were selected for forwarding research. Table 3 performs several statistical data, suitable to the five reference points chosen. During the winter time, the highest value occurs at P14 (5.1 ms^{-1}), abide by P13 and P20 (5 ms^{-1}). In total time, the lowest value reveals at P7 (3.7 ms^{-1}). Regarding the maximum wind speed, the maximum value at the 95th percentile appears during the winter, at P2 (10.3 ms^{-1}) and for the total time, at P20 (9.2 ms^{-1}), while a minimum value appears at P7 (2.3 ms^{-1}).

Table 3. Wind speed statistics, considering the satellite data corresponding to the reference points P2, P7, P13, P14 and P20.

V_W statistics/point	Time period	Number of data	Missing data (*NaN*)	50th (ms^{-1})	95th (ms^{-1})	Mode (ms^{-1})	Std. (ms^{-1})	Skew	Kurt	%	
										< 3 ms^{-1}	3–20.2 ms^{-1}
P2 (31 °E, 42 °N)	Total	1926	11	4.1	9.0	4.1	2.30	1.10	4.84	26.47	72.94
	Winter	1116	8	4.9	10.3	4.6	2.38	0.94	4.40	15.59	83.54
P7 (37 °E, 43 °N)	Total	1926	11	3.7	8.0	2.3	2.22	1.13	5.08	32.29	67.13
	Winter	1116	6	4.4	9.0	3.4	2.31	1.02	4.79	20.64	78.70
P13 (31 °E, 44 °N)	Total	1926	9	4.3	9.1	3.7	2.10	1.19	5.57	25.12	74.40
	Winter	1116	7	5.0	10.1	4.3	2.20	1.12	5.46	13.87	85.37
P14 (33 °E, 44 °N)	Total	1926	0	4.2	8.8	3.7	2.09	1.21	5.64	24.14	75.85
	Winter	1116	0	5.1	10.0	3.7	2.22	1.12	5.46	13.01	86.98
P20 (31 °E, 45 °N)	Total	1926	9	4.3	9.2	4.5	2.38	1.05	4.21	25.49	74.03
	Winter	1116	7	5.0	10.1	4.5	2.57	0.99	3.78	13.97	85.26

Another important source of data is the ERA-Interim project, maintained by the European Centre for Medium-Range Weather Forecasts (ECMWF), which is considered to be a reanalysis database.

According to the ECMWF data set, Figure 3 provides an overview of the wind conditions in the five reference points (P2, P7, P13, P14 and P20). From the analysis of the total time, it can be noticed that the points present values in the interval 10.3–8.8 ms^{-1}, more energetic conditions being reported by the point P2 (10.3 ms^{-1}), followed by P20, P13, P14 (9.5, 9.0, 9.0 ms^{-1}), respectively. The minimum of 8.0 ms^{-1} is accounted by P7. Comparing to the winter season, when the wind speeds located only between 10.0–10.3 ms^{-1} is more consistent.

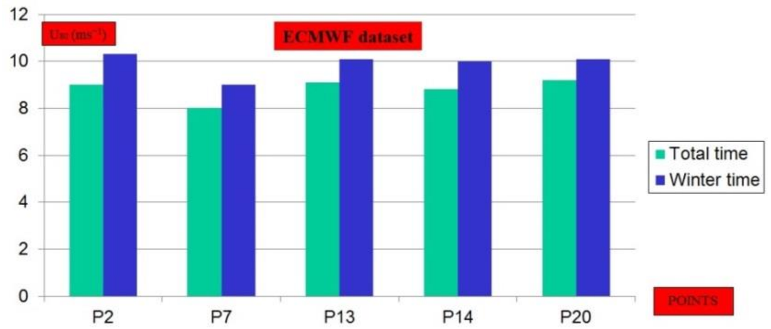

Fig. 3 Distribution of the average values of wind for summer and winter time conditions, for the 15-year interval 2000-2014, according to the ECMWF dataset

Figure 4 presents, in more details, the distribution of the values by wind classes, according to total time and winter season. From this distribution, it can be mentioned that most of the values are grouped in the range of 3-12 ms^{-1}, with the mention that, during the total time, the interval 3-9 ms^{-1} appears to be more important, as compared to the winter season, when the wind speeds located only between 6-9 ms^{-1} is more consistent [4].

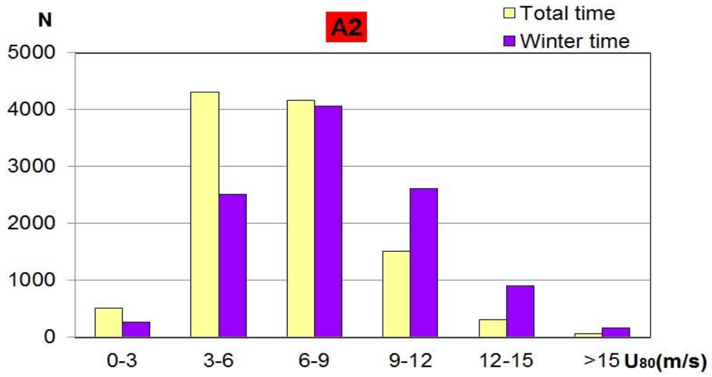

Fig. 4. Monthly maximum values corresponding to the point A2 for the interval September 2009-August 2015, as reflected by the AVISO dataset

The distribution of the maximum values is highlighted in Fig. 5, which indicates that the storms reported during the winter time represent a common event, during which a maximum of 20.1 ms^{-1} can be observed in November. During the summertime, these values are around 14 ms^{-1}, being reported several peaks in June (18.9 ms^{-1}) and July (16.4 ms^{-1}), respectively [4].

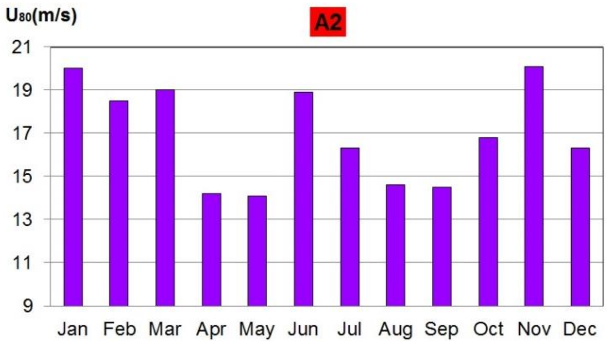

Fig. 5. Distribution of the wind conditions U_{80} histogram of the point A2 reported in the summer and winter time, for the 15-year interval 2000-2014, according to the ECMWF dataset

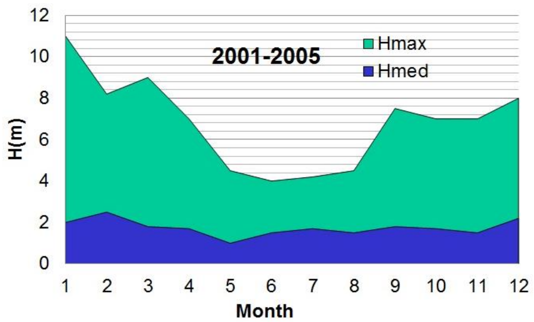

Fig. 6. Hs monthly average and maximums in the time interval 2001-2005, as registered at the Gloria unit

The statistic data show that, usually, the west side of the sea is more energetic. That is why data measured on the west side, at the Gloria drilling unit, for the period 2001- 2005, were performed below. As far as that goes considerable wave heights and wave periods, the average and maximum dates corresponding to each month, as registered at the Gloria unit, in the time interval 2001-2005, are presented in Figures 6 and 7 [4].

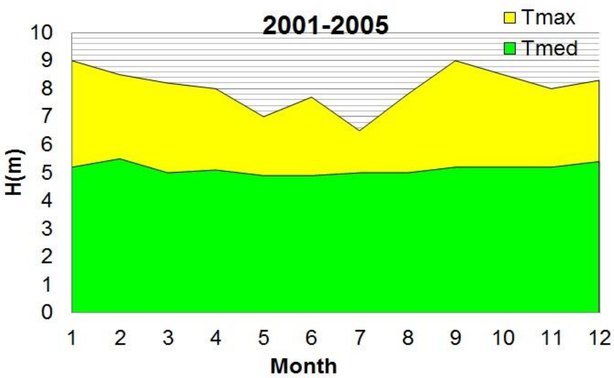

Fig. 7. Monthly average and maximums for the wave period in the time interval 2001-2005, as registered at the Gloria unit

4. CONCLUSIONS

In this work, it was performed a general estimation of the wind, wave and current conditions in the Black Sea, a special attention being paid to the extreme environmental events that may be faced in this geographical area. The research was based on the satellite measurements, coming from the AVISO platform and source of data ECMWF, the datasets available being processed for the time interval September 2009 - March 2016. From the analysis of the time series of the two most suitable parameters, wind speed and significant wave height are appropriate to the points A1-A15 and P1-P21. Obviously, the points from western part seem to be located in a more energetic area. Regarding the storm conditions, it was highlighted the fact that the extreme events usually cover large areas in the Black Sea, with the mention that the south-western part of the sea seems to have the most significant wave resources, while the most significant wind conditions appear to be in the north-western side of the sea, in A2. The results presented in this paper can be considered relevant since they present that the extreme environmental conditions are distributed between the offshore and nearshore sectors, more dense values being registered in the western part of the sea, which also includes several relevant shipping routes. In this part, it is also situated the southern gate in the seventh Pan European transportation passage, which is the Danube-Maine-Rhine inland navigation system.

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