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Identification and analysis of available hydrometeorological data sources for the Black Sea littoral

V. Dobref[1], A. Pintilie[1], A. Toma[1], D. Atodiresei[1], E.G. Robe-Voinea[1] and V. Mocanu[1]

[1] "Mircea cel Bătrân" Naval Academy, Constanta, Romania
Corresponding author: A. Pintilie, e-mail address: alexandru.pintilie@anmb.ro

Abstract.Unlike most seas, which have a uniformly formed shelf, the continental shelf of the Black Sea is limited in extent, reaching its maximum values in the northwest. The characteristic width of the shelf along the other coasts is 2-12 km. Situated in the north-western part of the Black Sea, the Romanian coastline is about 244 km long, the predominant orientation of the shoreline is N-S, with relatively shallow depths. The northern limit is the Mosura Arm (45°12′ N and 29°40′ E) in the Danube Delta, and the southern limit is slightly south of Vama Veche (43°44′ N and 28°35′ E). The Romanian coastline is generally linear, except for harbor areas and coastal protection works, especially in the south. The present work aims to identify and analyze hydrometeorological data provided by Romanian coastal and satellite stations, in order to model the dynamics of the Black Sea hydrographic circulation.
Keywords: hydrometeorological models, meteorological conditions

1. Introduction

The Black Sea, considered an inland, continental sea, is situated between Europe, Anatolia and the Caucasus, covers an unrolled area of about 423,000 km^2 and contains a water volume of about 555,000 km^3. It has an average depth of 1315 m with a maximum depth of 2258 m. The geographical coordinates 40054'- 46038' latitude and 27027'- 41042' longitude, place it in the northern hemisphere, temperate zone. It communicates to the south-west with the Mediterranean Sea through the Bosphorus and Dardanelles Straits, and to the north with the Sea of Azov through the Kerch Strait [6].

Bordering Romania, Ukraine, Russia, Russia, Georgia, Turkey and Bulgaria, the Black Sea is characterized by an irregular shape, with the largest bays, Burgas and Varna, located in the western part (off the coast of Bulgaria), followed in the north-western part by Odessa and Karkinit bays in the north-western part, and Kalamit and Feodora bays in the northern part (off the coast of Ukraine). In the east are the bays of Novorossiysk and Gelendzhik (off the coast of Russia) and in the south the bays of Sinop and Samsun (off the coast of Turkey).

The bathymetry of the Black Sea consists of the continental platform (shelf) with depths of (100...200) m, continental slope, continental piedmont and abyssal plain [6], [3]. The configuration of the bathymetric line, as well as the presence of depressions and troughs, substantially influence the distribution of water masses, the direction and velocity of water currents.

2. N-NNW Black Sea wind regime datasets

The data set needed to determine the aerodynamic regime in the NW Black Sea is based on the information provided by the Maritime Hydrographic Directorate (DHM), following the processing of data and information provided by 6 automatic hydrometeorological stations located along the Romanian coastline, from North to South as shown in Fig. 1 and Table 1, for the period 2009-2021.

The wind direction in the Black Sea varies greatly depending on the time of the year of the analysis and the location of the measurements. During the cold season the wind is strong and consistent, while in the warm season it is light and variable. In addition to the prevailing winds, the aerodynamic regime in the NW Black Sea is also influenced by local meteorological patterns and the topographic characteristics of the coastlines.

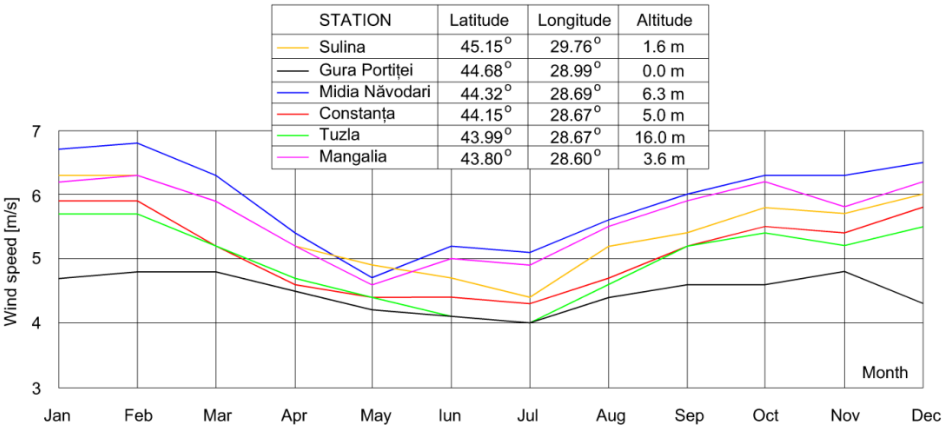


Figure 1. Monthly average wind distribution along the Romanian coast, 2009-2021 [6]

Along the Romanian coasts, depending on the season, the wind direction is predominantly oriented from the NW in winter and from the SE in summer, with the following particularities (see Fig. 2) [6]:

- in winter and fall, the wind is most intense and acts predominantly from the N-NW-W;
- in spring, wind intensity is transient and predominantly from the S-SE or S;
- in summer, the wind intensity is lowest and predominantly from the N-NWW or S.

Table 1. Average monthly wind values along the Romanian coast, 2009-2021 [6]

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constanța	5.9	5.6	5.2	4.6	4.4	4.4	4.3	4.7	5.2	5.5	5.4	5.8
Mangalia	6.2	6.2	5.9	5.2	5.6	5.0	4.9	5.5	5.9	6.2	5.8	6.2
Sulina	6.3	6.3	5.9	5.2	4.9	4.7	4.4	5.2	5.4	5.8	5.7	6.0
G.Portiței	4.7	5.0	4.8	4.5	4.2	4.1	4.0	4.4	4.6	4.6	4.8	4.3
Midia	6.7	6.6	6.3	5.4	4.7	5.2	5.1	5.6	6.0	6.3	6.3	6.5
Tuzla	5.7	5.6	5.2	4.7	4.4	4.1	4.0	4.6	5.2	5.4	5.2	5.5
Average	5.5	5.6	5.2	4.7	4.3	4.3	4.2	4.7	5.0	5.3	5.2	5.3
Direction	NW-N	N-S	N-S	S-SE	S-SE	S-N	NW-N	N-NW	N-NW	N-NW	N-NW	NW-W

3.Wave regime datasets in the N-NW Black Sea

3.1 Wind waves

Wind waves are the dominant type of waves and result from the transfer of wind energy between air and water surface.

The significant wind wave height Hs is proportional to the square of the wind speed U and the square root of the fetch F:

$$H_s = 0,031 \cdot U^2 \quad [\mathrm{m}], \tag{1}$$

respectively,

$$H_s = 0,36 \cdot \sqrt{F} \quad [\mathrm{m}], \tag{2}$$

where:

H_s – significant wave height in m; U – wind speed in m/s,F – fetch, i.e. the distance over which the wind holds its direction in km.

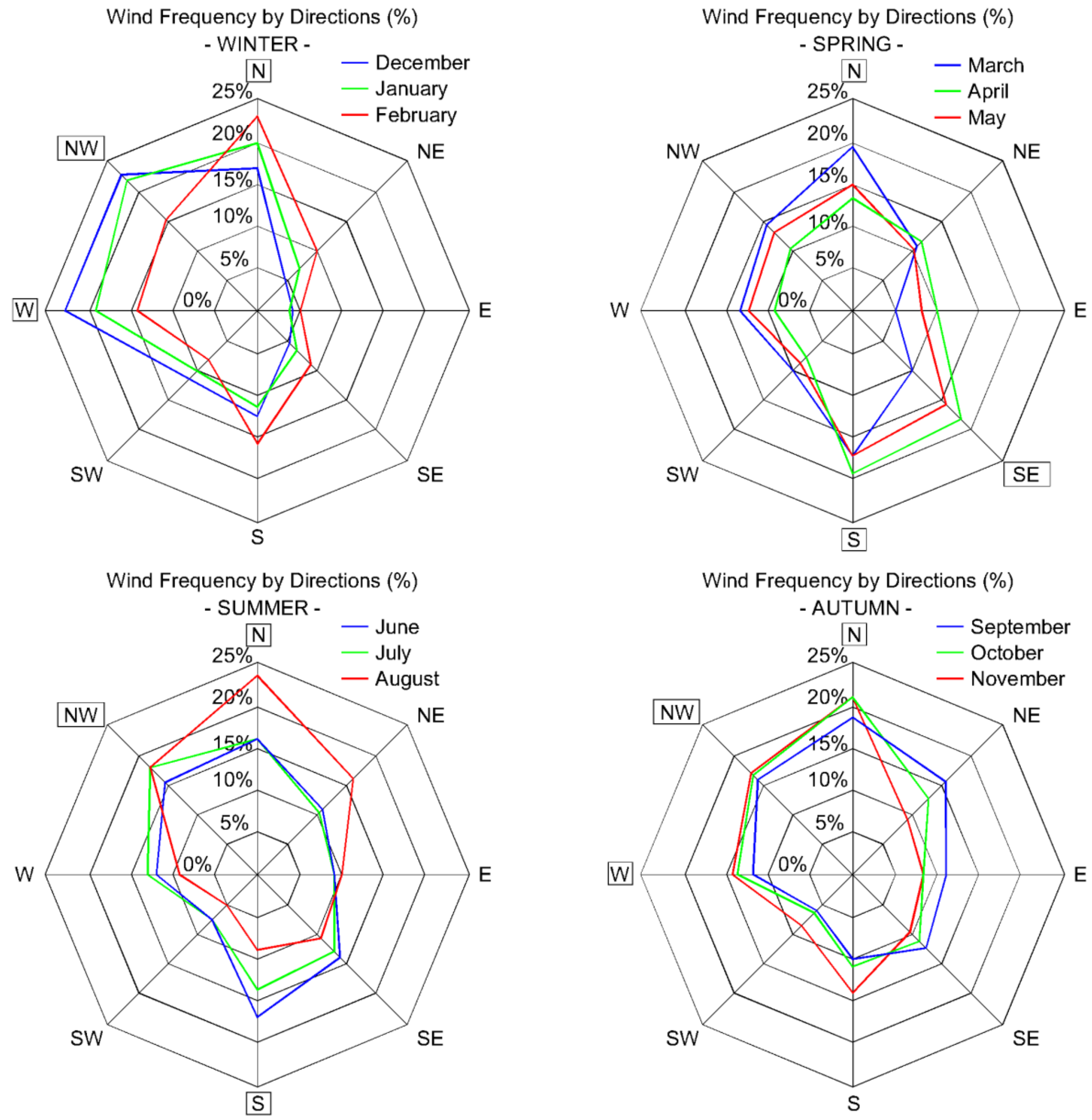


Figure 2. Predominant wind directions by season [6]

The usual method of wind-wave analysis is to use the S-B-M wind-wave correlation nomogram, developed by Sverdrup and Munk (1946) and Bretschneider (1952) respectively (see Fig. 3) [7]. Thus, knowing the wind speed U, the time interval D in which the wind maintains its direction and the distance F over which the wind maintains its direction, the significant height H_s and the period of the spectral maximum T_p of the wind wave can be determined.

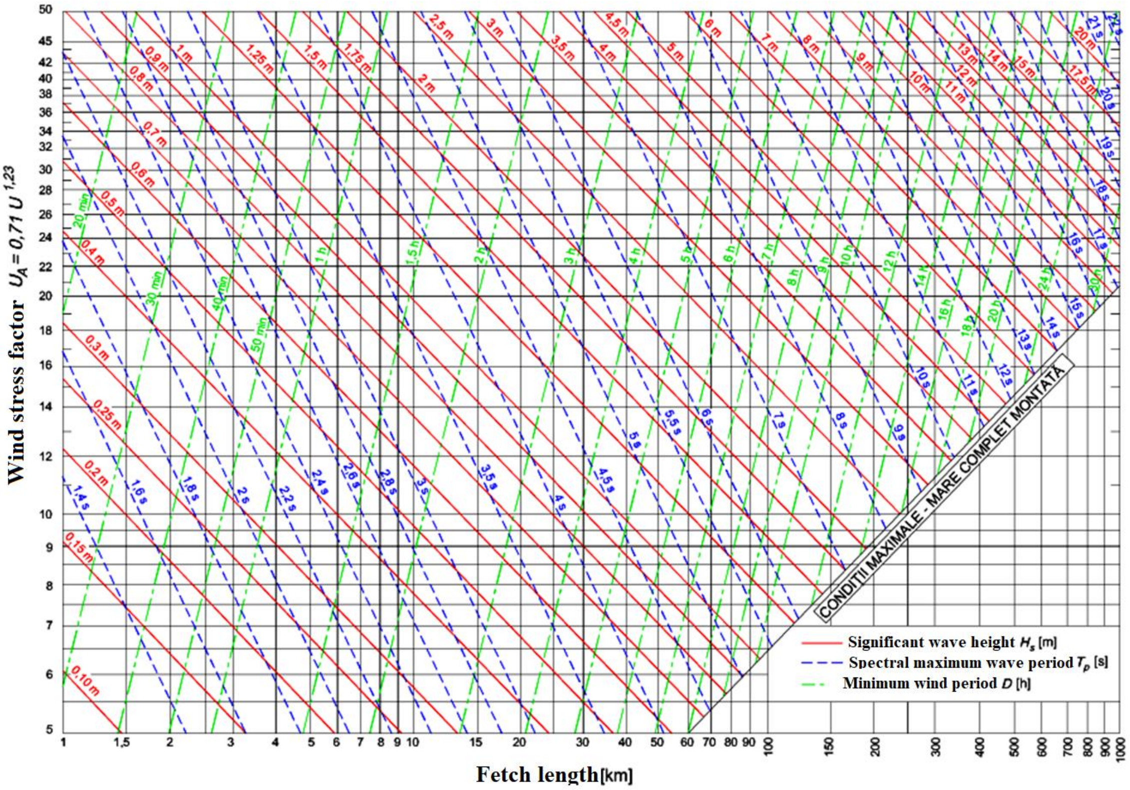


Figure 3.S-B-M Nomogram of wind-wind-valley correlation

As the sea state of agitation at any given time is the result of a complex phenomenon characterized by waves of different heights, lengths, directions and frequencies, the complete method of wind wave analysis is spectral analysis, which provides the distribution of wave energy between different frequencies and wavelengths.

Long-term wave spectra in the Black Sea have been analyzed by several specialists using various methods based on satellite altimetry measurements, measurements with floating buoys or numerical computer modeling methods.

Thus, using the SWAN (Simulating WAve Nearshore) model, developed by Delft University of Technology, the authors of the paper [1] analyzed directional wave spectra for a 42-year period (1979...2020), specific to the Black Sea. Out of the 25 offshore locations selected for analysis, in the present paper we are interested in the locations located in the north-western part of the Black Sea basin and along the Romanian coastline (S3, S4, S8) (see Fig. 4 and Table 2).

Table 2.Geographical characteristics of offshore locations selected for analysis [1]

Station	Longitude	Latitude	Depth [m]	Distance from the coastal line [°]
S3	31	45.5	- 12.0	0.501
S4	30	44.5	- 65.0	0.521
S8	29	43.5	-79.0	0.393

The average spectral density of waves in the V-NV Black Sea, i.e. the distribution of the total average wave energy per unit area, as a function of carrier wave frequency, for the interval (1979-2020) is plotted in Fig. 5, which validates the wave propagation trend along the Romanian coast in N-E-SE directions.

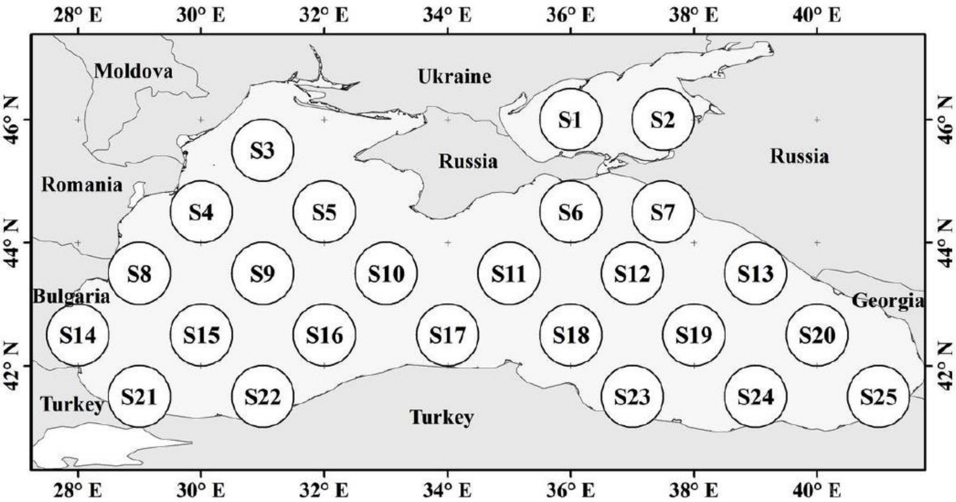


Figure 4. Geographical location of offshore locations selected for analysis [1]

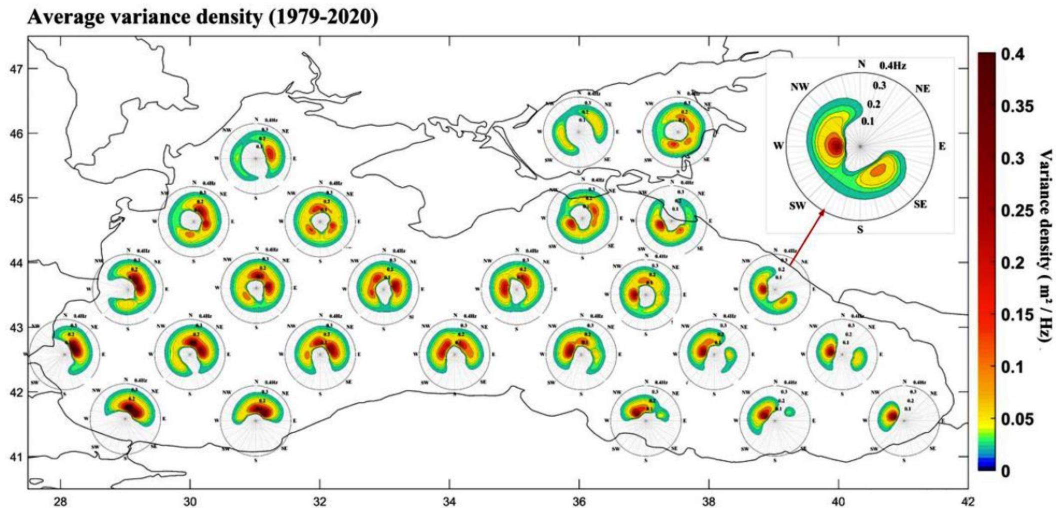


Figure 5. Multiannual average wave spectral density in the V-NW Black Sea, 1979-2020 [1]

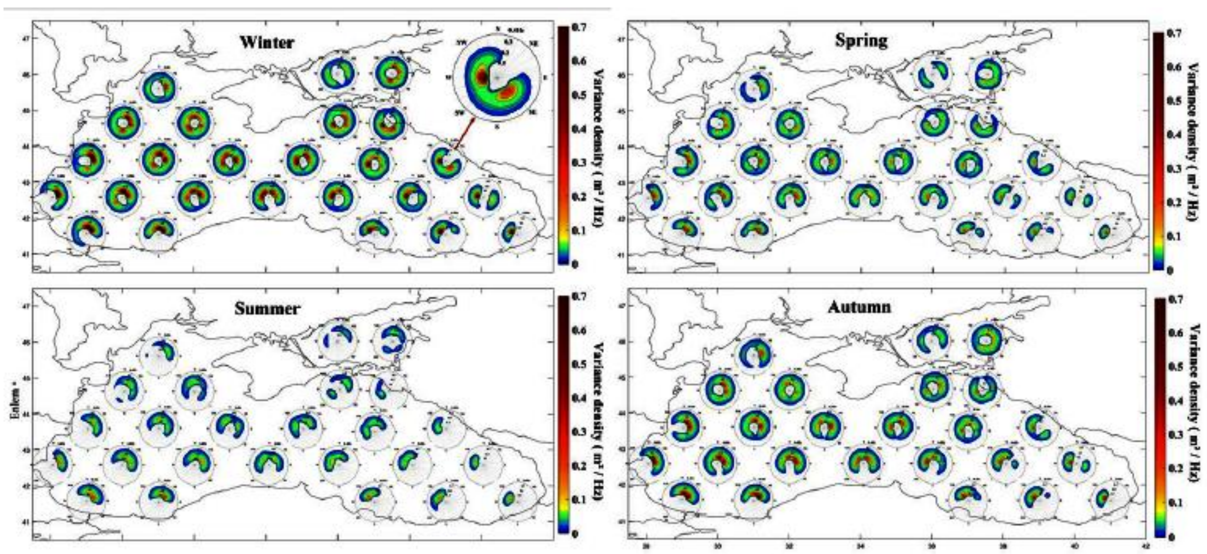


Figure 6. Seasonal average wave spectral density in the V-NW Black Sea, 1979-2020 [1]

On a seasonal scale, there is a clear variability in wave spectral density, as can be seen in Fig. 6. The most energetic seasons in terms of wave spectral density are the cold seasons (winter, fall), followed by the transient spring season, while the warm summer season is the lowest in terms of energy.

3.2 Ocean swell

Swell waves are oscillations of the sea surface after the wind has ceased and propagate due to inertia. Swell waves are usually longer than wind waves, have steeper slopes, rounded crests and regular, almost symmetrical shapes.

Swell waves fan out at an angle of maximum 900 centered on the wind direction, and their height and equivalent energy (energy per linear meter of crest) decrease rapidly as they leave the area of generation, with the total energy remaining constant in the expanding arc (see Fig. 7).

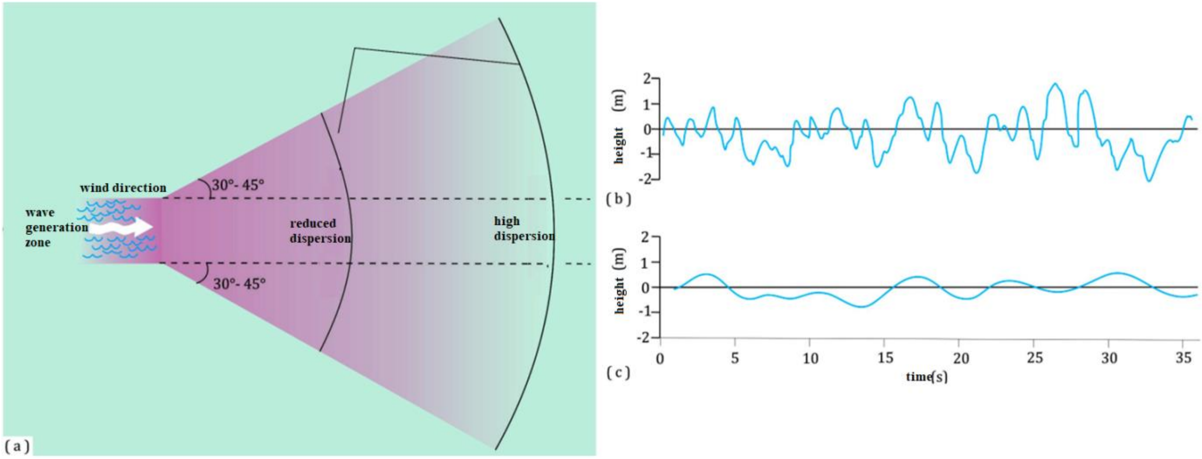


Figure 7.a) Propagation of the storm swell in relation to the area of generation; b) Height of the storm swell in the area of generation; c) Height of the swell at large distance from the source of generation

Due to the random wind regime in the N-NW part of the Black Sea, situations of overlap of swell waves formed offshore with wind waves formed in the coastal zone are frequent, which has been studied in [3].

Thus, the frequency of seasonal formation of the two types of waves is centralized in Table 3, and the values of the monthly mean frequencies of waves in the N-NW Black Sea, regardless of their nature, depending on the degree of sea agitation according to the Beaufort Scale, for a number of 6102 values measured in 2018, are centralized in Table 4 and plotted in Fig. 8.

Table 3.Frequency of seasonal wind and swell wave formation in the N-NWW Black Sea [3]

Wave type		Number of measurements	Seasonal frequency [%]			
			Cold season	Warm season	Mid season	Annual frequency
Wind		1952	47	27	22	32
swell		2623	27	42	59	43
Combining waves without separation	Wind	184	4	4	2	3
	swell	793	16	15	8	13
Wave combining with separation	Wind	123	1	2	2	2
	swell	427	5	10	7	7
Total		6102	100	100	100	100

Table 4.Values of monthly average wave frequencies in the N-NV Black Sea [3]

Sea state (Beaufort scale)	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1	6	12	17	27	33	41	44	25	26	18	15	11
2-3	34	41	45	57	51	44	42	54	48	38	37	39
4-5	42	35	32	25	15	14	12	19	23	39	36	37
6-7	17	10	5	1	1	1	1	1	2	5	11	11
8-9	2	1	0	0	0	0	0	0	0	0	1	1

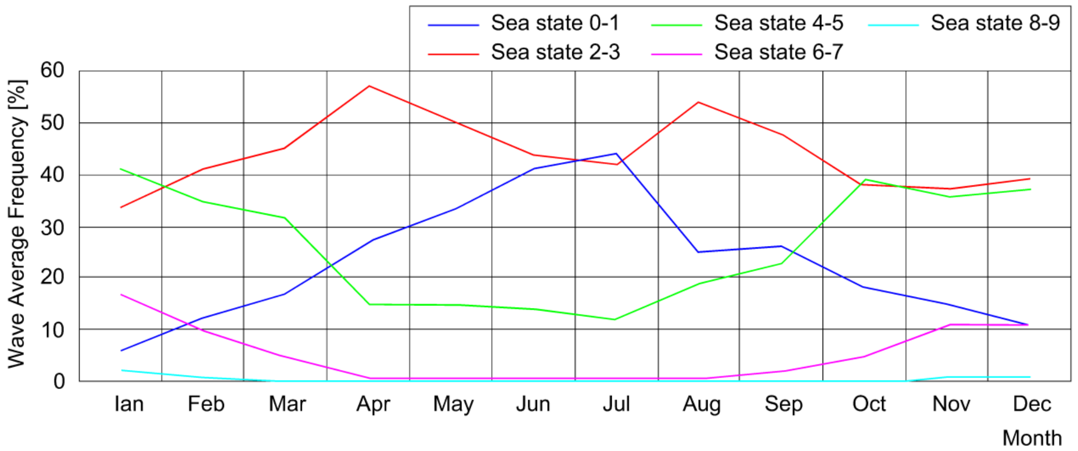


Figure 8. Average monthly wave frequencies in the N-NW Black Sea [3]

3.3 Breaker waves

As long as waves propagate in deep water, the only significant dynamical process is that of dispersion, with the formation of oil and wave clusters. As the waves approach the shore, where the water depth progressively decreases, a series of transformations take place that lead to a major change in the wave characteristics, except for the wave period, which remains constant.

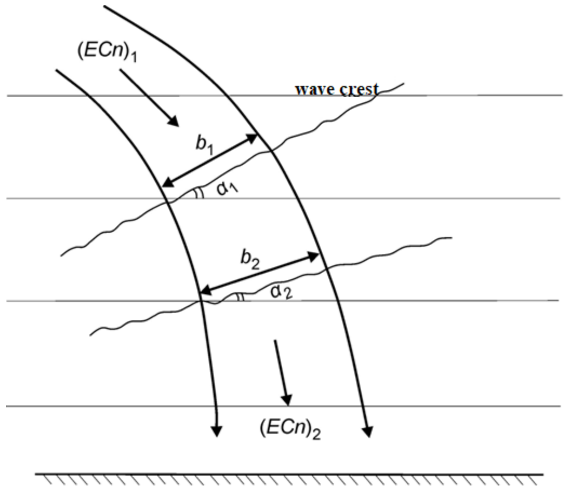


Figure 9. Wave refraction process near the shore [5]

Breaker waves occur near the shore, when the wave speed slows down and the wave crests, which are approaching each other, collapse forward by deferlation. The water particles no longer have an orbital motion, but a linear, shoreward-directed motion as a result of the release of shoreward-directed energy.

When the wave approaches the shore at an angle, the water depth varies along the wave crest. Since the speed of wave motion depends on the water depth, the part of the crest at deeper water depths will move faster than the crest at shallower water depths. The process of rotation of the wave crest as it tends to become parallel to the shoreline is called wave refraction [5] and plays an important role in the dynamics of sediment and floating object transport (see Fig. 9).

Another phenomenon that modifies wave characteristics near the shore is wave diffraction, i.e. the deviation of the direction of wave motion when encountering obstacles (submerged shoal, reef, jetty, island, etc.), based on the Huygens principle (see Fig. 10). The wave diffraction process reduces wave height and wave energy. In wave diffraction, the most important dynamic process is the transfer of wave energy along the crests from the wave sector directly affected by the obstacle to the free part of the rotating wave, which allows the wave energy to be transmitted to the sheltered area (semi-enclosed bays, harbor entrance, sheltered part of breakwaters, etc.) [7].

Figure 10. The wave diffraction phenomenon [10]

4.N-NNW Black Sea current regime datasets

The current regime is influenced by winds, river discharge, waves, water density distribution, coastal contours and the relief of the seabed.

The general direction of circulation of marine currents is determined by the rotation of the Earth (the Coriolis effect) which, in the northern hemisphere, causes currents to deviate to the right of the direction of wind propagation.

Depending on where the marine currents are formed, we speak of surface currents and deep currents. Only surface currents are analyzed in this study.

4.1 Wind-induced surface currents (drift currents)

In the analysis of the wind-induced surface currents for the Romanian coastal area, the Ekman effect is taken into account, which causes the surface currents to deviate to the right with respect to the wind direction with a maximum angle of 450 (see Fig. 11).

Previous research and studies carried out by various specialists lead to the following conclusions (see Fig. 12):

- during the cold season, due to the dominant wind direction in the N and NW sectors and the morphology of the Romanian coast, oriented in the N-S direction, the wind currents have the dominant direction oriented from N to S and manifest themselves in the immediate vicinity of the shore (cyclonic direction);
- during the warm season, due to the dominant wind direction from the S and SE sectors and the morphology of the Romanian coast, with a S-N orientation, the wind currents have a dominant S-N orientation, are offshore and tend to keep the coastal current from the North close to the shore (anticyclonic direction).

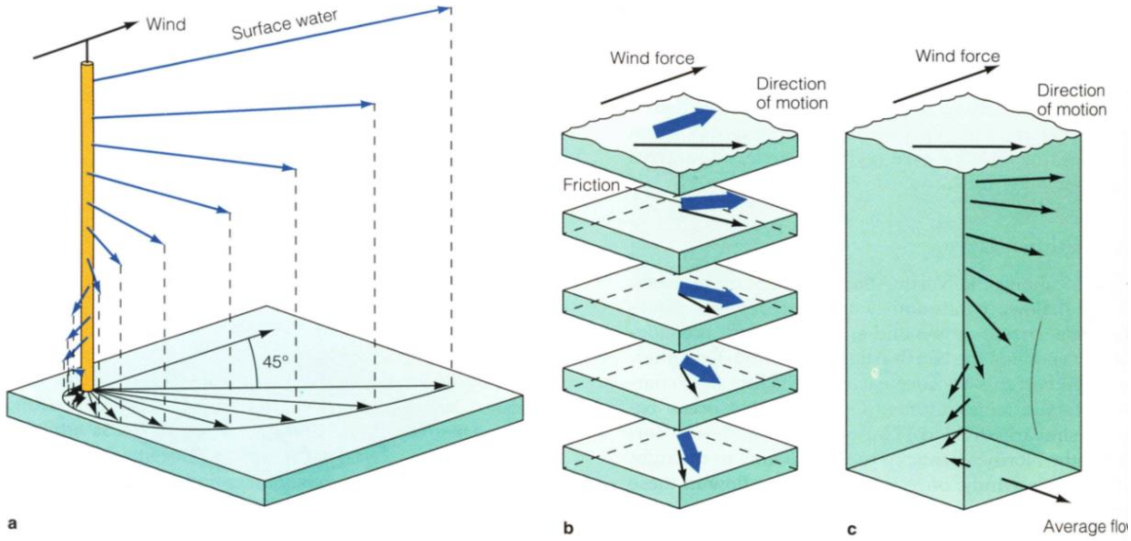


Figure 11. Distribution of the vertical distribution of the tangential wind velocity current on the sea surface [5]

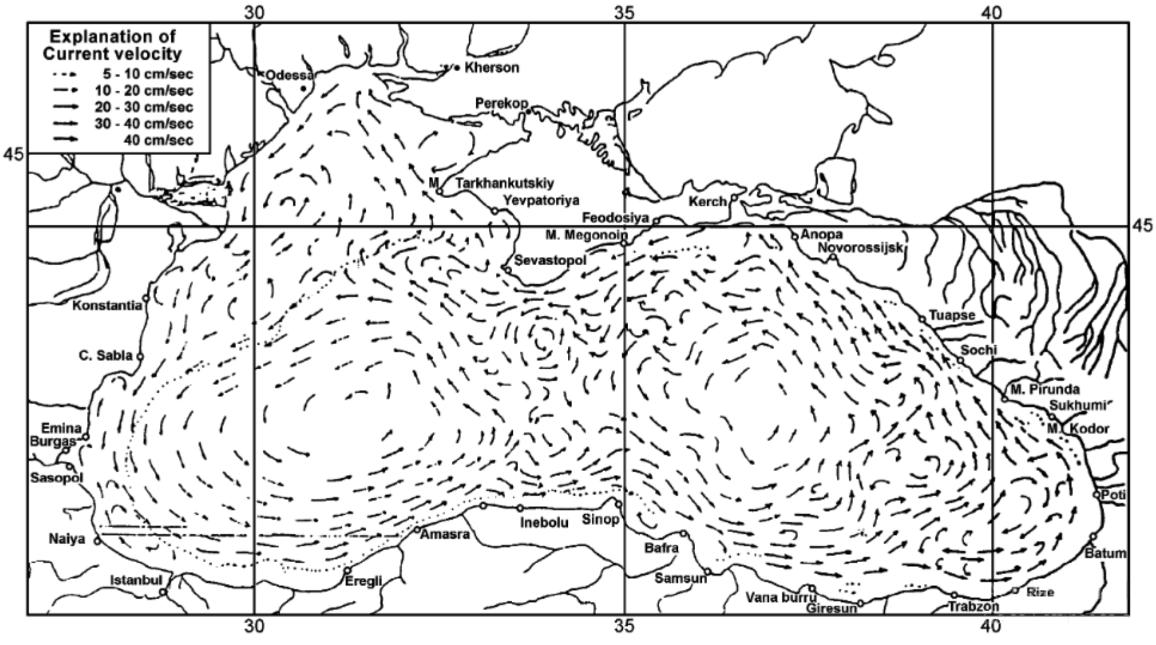


Figure 12. General circulation of marine currents in the Black Sea, after Neumann, 1942 [2]

In fact, the dynamics of wind currents along the Romanian coastline is also given by their annual frequency as shown in Fig. 13.

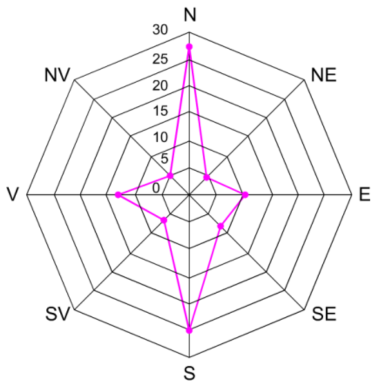


Figure 13. Annual frequency of dominant wind currents along the Romanian coast [9]

4.2 Wave-induced surface currents (shore currents)

Wave-induced surface currents occur in the littoral breaking zone and, depending on the direction of wave motion, the currents may move longitudinally along the shoreline or transversely perpendicular to the shoreline (see Fig. 14).

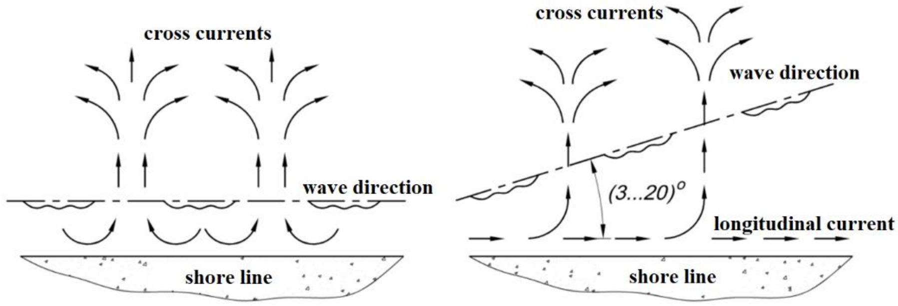


Figure 14. Longitudinal and transverse shore currents generation

Wave breaking is the fundamental process by which shore currents are formed, where the orbital motion of water particles is transformed into linear translational motion.

Longitudinal shore currents develop over long distances at wave angles of incidence of (3...20)0 to the shoreline, mobilize large volumes of water and sediment, and can only be interrupted by prominent obstacles (harbours, breakwaters, etc.).

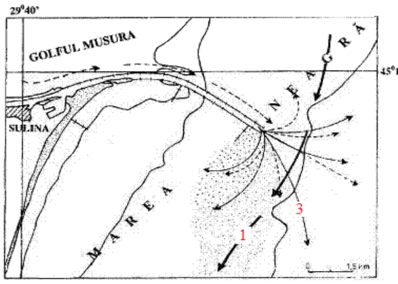
Cross-shore currents (Rip currents) are a consequence of local sea level rise in the breach zone and are a sea level equalizing pathway, with water being transported from the breach zone out to sea. Rip currents are formed when the waves are high and intense, generate breaches in the wave fronts, are strong, reaching speeds of (0.5...3) m/s, are narrow, (10...20) m wide and can advance offshore up to 800 m (in Romania up to 150 m) [8].

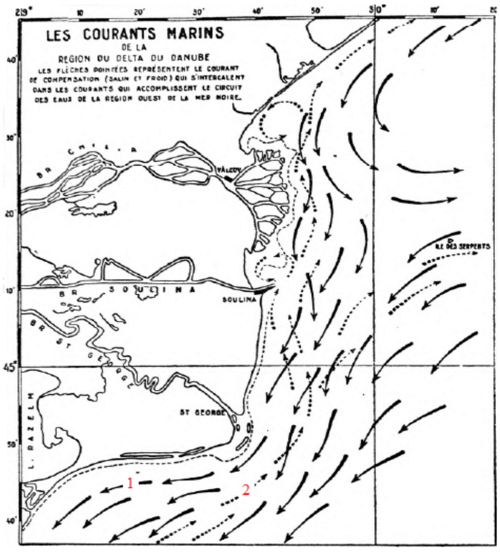
4.3 Surface currents caused by the flow of water in the Danube River (flow currents)

In analyzing the surface currents caused by the Danube River water flow, the fan-shaped distribution of river currents at the mouths of the Danube River in the Black Sea is taken into account, as can be seen in Fig. 15, a.

The velocity of the surface currents due to the flow of the Danube River decreases rapidly as it flows into the sea, then they are integrated into the main current circulation along the Romanian coast, as can be seen in Fig. 15, b.

The influence of the Danube River flow on the circulation of the surface currents in the N-NW Black Sea depends largely on the volume of water discharged, which requires a particular study.





a) *b*)

Figure 15.a) Distribution of river currents at the mouth of the Sulina Arm, after Romanescu 1996, 1999, 2002 (1. North main marine current; 2. South main marine current; 3. (b) General circulation of surface currents in the Danube Delta, after Ciocârdel 1937 [4]

5. Results and discussions

Due to the variable and unpredictable hydrographical and hydrometeorological conditions in the vicinity of the Romanian coastline, which can change within a few hours, it is difficult to establish a medium and long-term pattern of surface circulation in the N-NW Black Sea.

However, based on the available hydrometeorological data it is possible to establish a general seasonal circulation trend in the N-NNW Black Sea, which would provide the necessary information for the modeling of the surface hydrographic dynamics.

The validation of the hydrographic movement model of the Black Sea can be achieved as follows:

- in situ, by monitoring test buoys launched in the north of the Romanian coastline for at least 1 year;
- virtually, by simulating the surface hydrographic circulation with dedicated software (Swan, Ansys Fluid, etc.);
- satellite, by accessing hydrometeorological data provided by environmental prediction platforms (Windfinder, Windy, Copernicus, Weather etc.).

References

[1] Amarouche, K., Akpinar, A., *Long-term spectral wave climate in the Black Sea based on directional wave spectra*, Researche Square, 2023

[2] Bakan, G., Büyükgüngör, H., *The Black Sea*, Marine Pollution Bulletin, Vol. 41, 2000

[3] Boșneagu, R. et al., *Assessment for a buoy model in the Romanian Black Sea waters*, Journal of Envirommental Protection and Ecology 23, No 5, 2022

[4] Ciocârdel, R., *The general circulation of water in the Black Sea*, Hydrograpfic Review, 1937

[5] Mihailov, M.E., *Dinamica maselor de apă în Nord-Vestul Mării Negre*, Constanța, Editura Ex Ponto, 2017

[6] Nedelcu, L.I., Tănase, V.M., Rusu, E., *An evaluation of the wind energy along the Romanian Black Sea coast*, Inventions 2023, 8, 48

[7] Tătui, F., *Curs de oceanografie*, Universitatea din București, 2017

[8] ***, https://mindcraftstories.ro/stiinta/ucigasii-tacuti-din-marea-neagra-curentii-rip-te-trag-spre-ape-mai-adanci/ (Accessed in 15.02.2025)

[9] ***, https://www.hidro.ro/hidrometrie-fluviul-dunarea-si-marea-neagra/ (Accessed in 15.02.2025)

[10] ***, https://earth.google.com/web (Accessed in 02.03.2025)