An assessment model of exposure on coastal zone ecosystems

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Abstract. The article presents the analysis of climatic and hydrometeorological phenomena of the north-eastern part of the Black Sea in the water area of the Sea terminal. The research is carried out according to the Policy in the field of health protection and environmental in terms of the requirements of Russian and international standards. The analysis and statistical calculations involves data of the thirty-year series of the vertical profile currents. The main features of the sea climate (the Black Sea current) and seasonal weather features in this region are described. Furthermore, a major focus is paid to the characteristics and description of criteria for dangerous hydrometeorological phenomena.

Keywords: The climate of the Black Sea, meteorological regime, wave conditions of a water area, statistical parameters for currents, the analysis of criteria for dangerous hydrometeorological phenomena.

1. Introduction
Much current attention is paid to the ecological state of the environment and, in particular, the water system. The target program within the framework of the Water Strategy considers the analysis and control of the conservation of water bodies to a state favorable for human, plant and mammal life, as well as the impact of natural phenomena on living conditions, health and the economic component. A crucial issue is the study of natural phenomena, their chain interaction and impact on the environment and human [7].

The degree of influence of episodic natural hazards depends on their nature. It is wrong to believe that the development of modern new technologies enables to reduce the danger of negative natural phenomena. This statement can only apply to a certain class of static natural phenomena. Generally, the growth of marine infrastructure, the increase and complexity of production technologies and communications affects the growth of natural disasters. Accordingly, the economic damage is growing significantly.

Various climatic studies of natural factors in the form of precipitation, temperature regimes, winds provides to control changes in the stationarity of the runoff series. Such control plays a principle role with for active growth of most inhabited areas and industrial complexes. The results of such studies enables to solve not only topical issues in forecasting natural hazards, but also to control changes in the marine environment under the influence of climate change or economic activity [10].

2. Materials and Methods
Our article analyzes the desk processing and interpretation of the results in engineering and hydrometeorological surveys. The study was conducted in the north-eastern part of the Black Sea in the water area of the Caspian Pipeline Consortium (CPC) Sea Terminal on the coast near Yuzhnaya Ozereevka village in the Primorsky district in Novorossiysk. The sea depth in this area is 54-65 m.
The location of the site of the remote berthing devices (RBD) CPC-1 and RBD CPC-2 is shown in Figure 1. The surveys were carried out on two sites measuring 2x2 km for a zone bounded by two circles with the radius 1000 m, each with centers at points.

Figure 1. Layout of the site of the remote berthing devices of the RBD CPC-1 and RBD CPC-2

The main features of the sea climate are formed under the influence of macrocirculatory processes occurring in the Mediterranean climate region. In most expanses, the Black Sea climate is similar to the Mediterranean: warm and humid winters, hot and dry summers. The main seasonal weather features in the Mediterranean climatic region, and in particular over the Black Sea, are determined by the interaction of the Siberian and Azores maxima, the Asian minimum and the Mediterranean winter cyclone.

The main property of the waters of the Black Sea, which sharply distinguishes it from other marine reservoirs, is the presence of two different water masses: a surface layer reaching an average depth of 100-150 meters, and denser deep masses. Mixing between these layers is limited. The difference in the water density of the surface and deep layers is supported by the constant desalination of surface waters by a river runoff and the entry of salty waters of the Marmara Sea into the deep zone through the Bosphorus. Seasonal changes in sea level are created mainly due to intra-annual differences in the flow of a river runoff. Therefore, in the warm season, the level is higher, in the cold – lower. The magnitude of these fluctuations varies and is most significant in the areas of influence by continental runoff, where it reaches 30-40 cm.

According to the Code of Rules 20.13330.2016 "Loads and impacts" for Novorossiysk are accepted:
- by weight of snow cover - district II - 1.0 kPa;
- by wind pressure - district VI - 0.48 kPa;
- by the thickness of the ice wall - district III - 10 mm.;
- by the standard minimum air temperature, °C, - 25°C;
- by the standard maximum air temperature, °C, + 34°C.

The climate of the studied territory consists of the main climate-forming factors: radiation, circulation and the underlying surface.

According to the Code of Rules 131.13330.2018 "Building climatology", the total solar radiation (direct and scattered) on a horizontal surface with a cloudless sky in June is 915 MJ/m² (maximum for the year), in December – 198 MJ/m² (minimum for the year).

Atmospheric circulation is the main factor in the exchange of air masses over the Black Sea. Its role is great in moistening various areas of the sea, forming the weather. The most frequent sharp cold spells are observed when establishing the northern, north-eastern and north-western types of synoptic processes, and warming – when establishing the south-eastern and south-western types.
The underlying surface sufficiently influences on all components of the radiation and heat balances, as well as on the general circulation of the atmosphere and the formation of air masses. In the described region, two main types of underlying surface – water and land, have a significant and very different influence on the climate. Meteorological regime is affected by currents, snow and ice cover, structure features of the relief and vegetation of the land.

During engineering and hydrometeorological surveys, observations of the main parameters of the hydrological regime were organized. The authors analyzed and described the criteria of some dangerous hydrometeorological phenomena, as well as the speed and direction of currents, sea level, waves, temperature and salinity of sea water.

To calculate the wave conditions in the researched water area, such as the regime and dangerous parameters of waves from the moment of their origin to the development and transformation in shallow water, the spectral wave model MIKE21 SW is used, which is a part of the MIKE Zero by DHI.

The effects in the model are: wave refraction, wave diffraction, wave collapse, bottom, lateral friction, changes in the profile of the coastline, configuration of hydraulic structures, full and partial reflection of waves, nonlinear wave interactions.

3. Results

The data was processed using the "t_tide" program used to calculate the characteristics of tidal waves. Based on the results of calculations, 30-year series of temperature, salinity, density, sea level, and current velocities at several horizons were obtained.

For example, studies and characteristics of currents, their possible effects on underwater obstacles, objects due to wave resistance generate interest.

To analyze the nature of the currents and the vertical profile of the currents, the surface (0 – 2 m), intermediate (15 m.) and bottom (33 m.) horizons were selected [3].

Table 1 shows the calculated statistical parameters of the total flow over three horizons (surface, intermediate and bottom) based on the results of mathematical modeling.

| Horizon       | Minimum (cm/s) | Average (cm/s) | Maximum (cm/s) | Span (cm/s) | Average direction (°) |
|---------------|----------------|----------------|----------------|-------------|-----------------------|
| Surface       | 0,12           | 23,11          | 92,99          | 92,88       | 287                   |
| Intermediate  | 0,18           | 23,22          | 97,22          | 97,04       | 291                   |
| Near-bottom   | 0,25           | 22,88          | 88,46          | 88,22       | 292                   |

Tables 2-4 provide information on the harmonic constants of the main tidal waves of currents on the surface, intermediate and bottom horizons [6]. The harmonics S2, M2 and P1 make the greatest contribution to the tide level, and S2 makes the greatest contribution from these harmonics.

Table 2. Harmonic constants of the eight main tidal waves for surface horizon currents according to modeling data for RBD-1

| Wave | Amplitude U | Phase U | Amplitude V | Phase V | Angle of ellipse inclination | Large half-axis | Small half-axis |
|------|-------------|---------|-------------|---------|------------------------------|-----------------|-----------------|
| Q1   | 0,93        | 108     | 0,27        | 59      | 9                            | 1,02            | 0,71            |
| O1   | 1,43        | 181     | 0,46        | 165     | 177                          | 1,48            | 0,34            |
| P1   | 0,92        | 98      | 1,67        | 69      | 47                           | 1,77            | 0,23            |
| K1   | 1,08        | 0       | 2,30        | 256     | 98                           | 1,75            | 1,06            |
| N2   | 0,75        | 179     | 0,29        | 74      | 154                          | 0,74            | 0,47            |
| M2   | 0,40        | 271     | 0,15        | 18      | 16                           | 0,37            | 0,23            |
| S2   | 2,48        | 1345    | 2,15        | 87      | 30                           | 2,85            | 1,74            |
| K2   | 2,19        | 170     | 1,59        | 106     | 1                            | 2,24            | 1,82            |
Table 3. Harmonic constants of the eight main tidal waves for intermediate horizon currents according to modeling data for RBD -1

| Wave | Amplitude U | Phase U | Amplitude V | Phase V | Angle of ellipse inclination | Large half-axis | Small half-axis |
|------|-------------|---------|-------------|---------|------------------------------|-----------------|-----------------|
| Q1   | 0.70        | 97      | 0.78        | 264     | 144                          | 1.20            | 0.29            |
| O1   | 2.76        | 194     | 0.48        | 110     | 173                          | 2.74            | 0.84            |
| P1   | 1.30        | 17      | 4.15        | 99      | 102                          | 2.64            | 1.58            |
| K1   | 1.09        | 331     | 3.80        | 313     | 69                           | 2.28            | 0.03            |
| N2   | 0.84        | 179     | 0.36        | 42      | 145                          | 0.94            | 0.47            |
| M2   | 0.13        | 11      | 0.17        | 167     | 57                           | 0.31            | 0.02            |
| S2   | 3.02        | 131     | 1.48        | 72      | 179                          | 3.32            | 1.05            |
| K2   | 2.87        | 168     | 1.60        | 89      | 166                          | 3.16            | 1.51            |

Table 4. Harmonic constants of the eight main tidal waves for bottom horizon currents according to modeling data for RBD -1

| Wave | Amplitude U | Phase U | Amplitude V | Phase V | Angle of ellipse inclination | Large half-axis | Small half-axis |
|------|-------------|---------|-------------|---------|------------------------------|-----------------|-----------------|
| Q1   | 0.93        | 108     | 0.27        | 59      | 9                            | 1,02            | 0.71            |
| O1   | 1.43        | 181     | 0.46        | 165     | 177                          | 1.48            | 0.34            |
| P1   | 0.92        | 98      | 1.67        | 69      | 47                           | 1.77            | 0.23            |
| K1   | 1.08        | 0       | 2.30        | 256     | 98                           | 1.75            | 1.06            |
| N2   | 0.75        | 179     | 0.29        | 74      | 154                          | 0.74            | 0.47            |
| M2   | 0.40        | 271     | 0.15        | 19      | 16                           | 0.37            | 0.23            |
| S2   | 2.48        | 135     | 2.15        | 87      | 30                           | 2.85            | 1.74            |
| K2   | 2.19        | 170     | 1.59        | 106     | 1                            | 2.241           | 1.82            |

Figures 2-4 show the parameters of ellipses based on tabular data.

Table 5 shows the calculated extreme flow velocities that are possible 1 time in 1, 5, 10, 25 and 50 years by the direction in terms of the mathematical modeling data. The calculation results show that at all horizons, the maximum flow velocities possible once every 50 years are observed at the currents of the western points. They are 113.08 cm/s, 108.82 cm/s and 103.92 cm/s for the surface, intermediate and bottom horizons, respectively.
Table 5. Extreme flow velocities (cm/s) in the near-surface, middle and bottom horizons are possible 1 time in 1, 5, 10, 25, 50 years according to mathematical modeling data for RBD -1

| Repeatability, years | N  | NE | E  | SE | S  | SW | W  | NW |
|---------------------|----|----|----|----|----|----|----|----|
| Near-surface horizon |    |    |    |    |    |    |    |    |
| 1                   | 76.60 | 51.41 | 32.11 | 50.71 | 68.24 | 47.14 | 25.33 | 42.22 |
| 5                   | 88.97 | 62.37 | 36.14 | 57.20 | 77.20 | 58.41 | 31.63 | 51.26 |
| 1                   | 29.96 | 22.67 | 35.95 | 39.03 | 21.22 | 33.18 | 76.82 | 62.50 |
| 5                   | 39.04 | 29.19 | 46.94 | 53.73 | 27.69 | 39.68 | 92.30 | 71.64 |
| 10                  | 42.74 | 31.84 | 51.42 | 59.72 | 30.33 | 42.33 | 98.62 | 75.37 |
| 25                  | 47.58 | 35.31 | 57.28 | 67.55 | 33.78 | 45.79 | 106.87 | 80.24 |
| 50                  | 51.22 | 37.93 | 61.68 | 73.44 | 36.38 | 48.39 | 113.08 | 83.90 |
| 100                 | 54.85 | 40.53 | 66.08 | 79.33 | 38.97 | 51.00 | 119.28 | 87.56 |
| Intermediate horizon |     |    |    |    |    |    |    |    |
| 1                   | 21.44 | 19.12 | 33.61 | 30.37 | 11.21 | 19.89 | 80.36 | 62.95 |
| 5                   | 28.72 | 25.93 | 43.43 | 42.75 | 14.72 | 28.51 | 92.51 | 72.70 |
| 10                  | 31.69 | 28.71 | 47.43 | 47.80 | 16.15 | 32.02 | 97.47 | 76.67 |
| 25                  | 35.56 | 32.34 | 52.66 | 54.40 | 18.02 | 36.62 | 103.95 | 81.87 |
| 50                  | 38.48 | 35.08 | 56.60 | 59.36 | 19.43 | 40.07 | 108.82 | 85.78 |
| 100                 | 41.39 | 37.80 | 60.52 | 64.32 | 20.83 | 43.52 | 113.69 | 89.68 |
| Bottom horizon       |     |    |    |    |    |    |    |    |
| 1                   | 19.45 | 18.00 | 31.14 | 30.18 | 10.20 | 18.03 | 77.14 | 64.05 |
| 5                   | 24.28 | 22.10 | 41.34 | 44.22 | 13.94 | 25.31 | 88.57 | 73.43 |
| 10                  | 26.25 | 23.77 | 45.50 | 49.95 | 15.46 | 28.28 | 93.24 | 77.25 |
| 25                  | 28.83 | 25.96 | 50.94 | 57.43 | 17.45 | 32.16 | 99.33 | 82.24 |
| 50                  | 30.77 | 27.61 | 55.04 | 63.06 | 18.94 | 35.08 | 103.92 | 86.00 |
| 100                 | 32.70 | 29.25 | 59.12 | 68.68 | 20.44 | 38.00 | 108.49 | 89.75 |

Thus, based on the results of calculations, a number of characteristics (temperature, salinity, density, sea level, current velocities on several horizons) are analyzed provide analyzing and making forecasts, calculations for various marine economic activities.

4. Discussion
The most important studies are focused on water or air environments, the extreme appearance of which can result in great economic, environmental and human damage. The major attention should be paid to the study of dangerous phenomena that lead to man-made accidents and catastrophes. Exposure to particularly dangerous objects requires to monitor and predict situations caused by dangerous natural phenomena.

Dangerous hydrometeorological phenomena (DHP) are assumed as a complex of meteorological phenomena and quantities that pose a threat to the economy and (or) the population by their intensity or duration. Such evaluating values are quantitative or qualitative criteria with a description of the characteristics.

Various climatic conditions determine the spectrum of DHP. The seas surrounding the territory of Russia include 13 species of DHP, which are monitored for detecting, predicting and warning. DHP in the work area include strong winds, tornadoes, strong waves, storm surges and draft, severe icing of ships, extreme icing, etc. (Table 6). The criteria of DHP are established either according to the probability of occurrence of phenomena, or "directly" taking into account the results of the analysis of hydrometeorological
observations for a long-term period. A combination of DHP with intensity and/or strength out of the criteria, but is close to it, also belongs to the DHP.

Table 6. Characteristics and criteria of some dangerous hydrometeorological phenomena

| DHP name            | DHG criteria                                                                 | Type and nature of the impact of the phenomenon | Distribution area                                      |
|---------------------|-------------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------------|
| Very strong wind    | The maximum wind speed (including gusts) is not less than 30 m/s, (except for the coastal zone of the Black Sea from Anapa to Tuapse), in the coastal zone of the Black Sea from Anapa to Tuapse 35 m/s or more | Dynamic impact on structures that reaches a destructive force in the area of the process | Bound along the front extending in the direction of the trajectory of the process |
| Tornado             | A strong small-scale vortex with a vertical axis in the form of a column or funnel of any intensity, directed from the cloud to the underlying surface |                                                |                                                       |
| Strong excitement   | Wave height: at least 6.0 m – on the Black Sea (except for the coastal zone within the municipal formation of the resort city of Sochi) |                                                |                                                       |
| Intense ice drift   | The drift of ice fields (ice floes of at least 500 m in size) at a speed of at least 1 km/h | Weighting of structures due to their coating with ice, frost | Separate natural areas with different process indicators |
| Icing of ships      | Fast and very fast (at least 0.7 cm/h) icing of ships                         |                                                |                                                       |
| Run-up phenomena    | Water levels are below dangerous levels at which navigation stops, fish dies, ships are damaged, or above dangerous levels at which settlements, coastal structures and objects are flooded | Flooding of structures located in the zone of impact of the process, the occurrence of a danger to the movement of water transport | The bottom of river valleys, the coastal zone of reservoirs, lakes and seas |
| Strong draft in the ports | Resonant wave vibrations of water in ports that cause cyclic horizontal movements of ships (at least 1 m) standing at the berth in ports | The occurrence of a danger to traffic due to limited visibility | Bound along the front extending in the direction of the trajectory of the process |
| Heavy fog at sea    | Fog with visibility of less than 100 m for 12 hours or more                  |                                                |                                                       |

According to numerical simulation data, the wind speed can exceed 25 m/s once every 5 years – in the directions E and S. The duration of storms with wind speeds >25 m/s on average does not exceed a day per year.
Waves with a significant wave height of more than 4 m have a repeatability of 0.03% per year, waves of 3% - security - 0.36%. The maximum duration of storms with a significant wave height of more than 4 m is 4 days in the survey area. Once a year, according to the simulation data, a significant wave height can reach 4.01 m (W direction).

During the warm period of the year, several cases of tornadoes are observed annually in the Azov-Black Sea basin. Their scale and consequences are different. The speed of tornado movement is on average 10 m/s. The wind speed in the tornado reaches 100 m/s.

Water tornadoes are often accompanied by cascades – a cloud or a column of water spray at the base of the tornado. The height of the cascade can reach several hundred meters, but most often - several tens of meters.

Despite the fact that the navigation period in the studied sector of the Black Sea is 12 months from December to March, icing of ships and surface parts of hydraulic structures is possible. In 80% of cases, icing in the north-eastern part of the sea is observed in the rear part of deep cyclones at a wind speed of 12-15 m/s, air temperature from minus 10 to minus 2°C and water temperature below minus 5°C.

The total number of cases of dangerous atmospheric phenomena is presented for the period 1977-2020 according to the data of the Krasnodar meteorology center (Table 7, Figure 5).

Table 7. The total number of dangerous atmospheric phenomena observed during 1977-2016.

| Atmospheric phenomena | Strong wind | Heavy showers / rains | Blizzard | Tornado over the sea | Tornado over the sea with access to land | Strong heat | Strong snowfall | Strong frost | Strong ice |
|-----------------------|-------------|-----------------------|----------|----------------------|-----------------------------------------|-------------|----------------|-------------|------------|
| The total cases in 1977-2016 | 47          | 6/5                   | 4        | 4                    | 1                                       | 11          | 3              | 1           | 1          |

Figure 5. The number of dangerous phenomena during 1977-2020

5. Conclusions

The conducted analysis, including dangerous phenomena, showed that taking into account such natural factors as waves, currents, wind, etc., is of practical interest for engineering technical structures and re-equipment of objects of various significance.
The systematization and classification of dangerous phenomena allows us to analyze the connections existing between the considered natural phenomena and take into account the conditions of their formation, distribution, frequency of manifestation during engineering developments.

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