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Original article

Synoptic Conditions for Storm Formation in the Black Sea in November 2023, and Hydrometeorological Monitoring at the Stationary Oceanographic Platform

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Abstract
Purpose. The purpose of the study is to analyze the circulation conditions for the formation and development of an extreme storm in the Black Sea in November 2023, as well as the dynamics of the storm process, based on the hydrometeorological monitoring data obtained at the Black Sea hydrophysical subsatellite polygon of Marine Hydrophysical Institute, RAS.
Methods and Results. The characteristics of the Black Sea cyclone (25–27 November 2023), and the factors that conditioned its intensive development were investigated using GFS, ICON (7-km resolution), and GEM synoptic charts and barotropic topography (Wetter3.de). Besides, aerological sounding data and archival instrumental observations were also applied. It is established that the cyclone was an extratropical one with signs of explosive cyclogenesis (a deepening of 25 hPa per day). The following key intensification factors were revealed: thermodynamic ones (frontal zone of the baric trough, high-altitude frontal zone, divergence of flows, temperature contrast in the 500–1000 hPa layer); dynamic ones (jet stream with vertical velocity gradient, inter-latitudinal temperature gradient, high pressure gradient, coincidence of wind directions near the ground and at altitude). It has been shown that climate warming and rising Black Sea water temperatures enhance evaporation that, in its turn, increases the probability of extreme cyclones.
Conclusions. A rather rare combination of large-scale and synoptic atmospheric processes over the Black and Aegean seas in late November 2023 resulted in the formation of a deep explosive extratropical cyclone and the development of an extreme Black Sea storm. Continuous automated measurements performed at the stationary oceanographic platform of the Black Sea hydrophysical subsatellite polygon (MHI RAS) under strong and hurricane-force wind speeds (up to 40 m/s) and wave heights (up to 7.14 m) made it possible to track the storm dynamics in greater detail than standard hydrometeorological observations can provide. The experimental data obtained under extreme storm conditions are of practical significance and will be useful for various applied studies.

Keywords: storm, wave recorder, extreme waves, extreme wind, wind waves, Black Sea, water temperature, air temperature

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Introduction

The Black Sea water area and coast are of key importance to Russia as a major transport and strategic hub, as well as one of the principal resort zones. This creates a high demand for reliable meteorological data, particularly on wind and wave conditions, which are essential both for hydrometeorological support of economic activities and for monitoring the state of marine and coastal ecosystems.

For any calculations related to wave parameters, a major problem remains the lack of long-term instrumental observation series. Therefore, wave characteristics are typically obtained through numerical modeling. Currently, at the Hydrometeorological Center of Russia, forecast maps of wind wave parameters for the Black Sea are generated based on calculations using the spectral Wavewatch III model (version 3.14) on a grid with a resolution of 10×10 km. The input parameters are operational forecast meteorological fields (wind speed, water and air temperature, ice cover extent) provided by the medium-range forecast systems of the Hydrometeorological Center of Russia and NCEP/NOAA. The output forecast parameters include: zonal and meridional wind speed components; significant wave height, length, and period, as well as characteristics of the most pronounced swell system [1], with a forecast lead time of up to 72 hours.

In recent years, extreme waves with heights of seven meters or more have frequently been recorded in the Black Sea region, generating both scientific and practical interest. The most severe wave activity is often observed in the southwestern and northeastern parts of the sea [1]. High storm waves in the Black Sea are more likely during the cold season. Their formation is facilitated by a long fetch over the sea area and the intensification of northeasterly winds. During the spring-summer season, winds from these directions are typically weaker, significantly reducing the frequency of storm waves [2]. However, under favorable conditions, storm waves of considerable height can develop – about 12 m, and in some cases up to 18 m [3]. The probability of anomalous waves (by the criterion $AI > 2$) in the coastal zone of the Black Sea under deep-water conditions is 3.3% [4].

Forecasting wind waves using predictive models is of great practical importance for various maritime and coastal industries. General circulation models, based on the equations of hydrodynamics and thermodynamics, calculate wind waves as a result of atmospheric and oceanic interactions, using data on hydrometeorological parameters [5].

The authors of [6], analyzing data from the storm in the Black Sea on 26–27 November 2023, concluded that all models significantly overestimate the calculated wave heights. Instrumental measurements and satellite remote sensing data remain the most accurate. At the same time, global reanalyses systematically underestimate wind speed by 1–4 m/s under strong wind conditions (> 12 m/s) and overestimate it under weak wind conditions (< 4 m/s) [7]. Improving the accuracy of extreme wave measurements is critically important for studying wave dynamics and enhancing storm warnings.

[1] ESIMO. *Forecast of Wind Wave Parameters in the Black Sea from 00:00.* [online] Available at: https://esimo.ru/dataview/viewresourse?resourceId=RU_Hydrometcentre_69 [Accessed: 10 October 2025].

The link between extreme storms and rising global air temperature is supported by a number of sources [2] [6–9]. Rising temperatures enhance evaporation, increasing atmospheric moisture content [3], which in turn leads to the development of dangerous storm cyclones. When a cyclone passes over a warm sea surface, atmospheric instability, driven by increased moisture content and heating of the lower troposphere, contributes to the rapid deepening of the cyclonic vortex via the mechanism of explosive cyclogenesis [10, 11].

A study of hurricanes in the Gulf of Mexico concluded that noticeable disturbances in atmospheric moisture content are recorded several days before storm intensification, persisting even after hurricanes move from the gulf to land [12]. This topic is also of interest for investigation in the context of the Black Sea.

The November 2023 storm is of particular significance for the authors of this article, as unique data were obtained during its passage using equipment for monitoring hydrometeorological parameters on an oceanographic platform [13]. To increase measurement reliability under extreme conditions, where traditional string wave recorders may fail [14], the MHI platform uses twisted resistive wave recorders, capable of accurately measuring wave heights up to 10 m.

During the cold season, especially in late autumn, the Black Sea acts as a regional heat source for the atmosphere. This leads to the formation of a baric trough in this region, influencing large-scale circulation processes. It is during this period that cold air advection from the north often occurs in the rear part of an upper-level trough over the warmed sea surface. The resulting temperature contrast between the two environments creates conditions for atmospheric instability, causing the genesis or deepening of southern cyclones. Such cyclones are often very similar to tropical ones in their origin and consequences.

As noted by B. P. Multanovsky [15], the Black Sea is the first transitional stage from the European regime to the monsoonal circulation of the Indian Ocean, and under certain conditions, tropical storms can form here. However, they are quite rare and usually form in late August – early September, when water temperatures are around 26 °C or higher. At lower water temperatures, extratropical cyclones form, outwardly similar to tropical ones, with central pressures down to 950 hPa, accompanied by storm-force winds. Strong wind shear and cold air intrusions in late autumn contribute to the development of such cyclones.

Advection of cold Arctic air during this season is a frequent phenomenon, occurring during meridional transport and the negative phase of the North Atlantic Oscillation (NAO) index [16]. The greater the total duration of Arctic air intrusion, the more significant the volume of incoming dry cold air and its impact on the weather conditions of the Black Sea region [17]. It is precisely during meridional transport in recent decades that an increasing number of cyclones with storm-force

[2] Shirshov Institute of Oceanology of RAS. [*Expert: The Upper Layer of the Black Sea Has Warmed by 2 Degrees in 30 Years, Severe Storms Will Become More Frequent*]. [online] Available at: https://ocean.ru/index.php/novosti-left/novosti-instituta/item/3337-ekspert-verkhnij-sloj-chernogo-morya-poteplel-na-2-gradusa-za-30-let-silnye-shtormy-budut-chashche [Accessed: 10 April 2025] (in Russian).

[3] Brutsaert, W., 1982. *Evaporation into the Atmosphere: Theory, History and Applications*. Environmental Fluid Mechanics Series, vol. 1. Dordrecht: Springer-Science and Business Media, 299 p.

winds have been forming [18]. Such disturbances develop in strongly elongated, meridionally oriented baric troughs moving northward. Meridional transport affects local changes in the relative vorticity, which increases with latitude, leading to the formation of a cyclonic eddy in an air mass moving southward. The studied cyclone of 26–27 November 2023, also formed under conditions of meridional air mass transport.

The purpose of this work is to estimate the synoptic conditions for the formation and development of the storm in the Black Sea on November 26–27, 2023 and to analyze the hydrometeorological data obtained during this event.

Equipment for hydrometeorological monitoring, materials and methods

The dynamics of temperature, wind, and wave regimes in November 2023 were tracked using data from 10-minute intervals (amounting to 4 303 sessions), obtained at the stationary oceanographic platform of the Black Sea hydrophysical subsatellite polygon of MHI (RAS) (hereafter referred to as the platform), located 600 m from the shore where the sea depth is about 30 m. Hydrometeorological measurements were conducted automatically using a hydrometeorological data acquisition system (developed by MHI), which includes a compact anemometer (measuring wind speeds up to 60 m/s), a twisted resistive wave recorder (measuring wave heights up to 10 m with a sampling frequency of 4 Hz), and sensors for atmospheric and sea temperature, relative humidity, and atmospheric pressure [13, 19]. The wave recorder, developed by specialists from the Oceanography Department, proved to be the only instrument capable of continuously and correctly registering measurement data under extreme storm conditions. All data underwent quality control, with unreliable fragments being discarded. Since wind speed measurements were taken at a height of 21 m above sea level, it was necessary to adjust them to the standard observation height (10 m). For this, a formula assuming the presence of a logarithmic sublayer was used:

$$U_{10} = U_{21} \frac{\ln \frac{10 + z_0}{z_0}}{\ln \frac{21 + z_0}{z_0}},$$

where z_0 is the roughness parameter.

It has been experimentally established [20] that the z_0 values for the sea surface in the region under consideration range from 10^{-4} to 10^{-3} m. For this study, an average value of $z_0 = 5 \cdot 10^{-4}$ m was adopted.

Archival data from coastal meteorological stations from the RP5 [4] website were used for comparison with data obtained at the platform (air and water temperature, atmospheric pressure, wind direction and speed).

Since the determining factor for wind conditions over the Black Sea is the structure of the baric field, an analysis of the synoptic situation and circulation conditions was carried out using daily charts from the synoptic archives of

[4] Weather Schedule. *Weather in 241 Countries around the World*. [online] Available at: https://rp5.ru [Accessed: 29 April 2025].

the American GFS, German ICON (high-resolution – 7 km), and Canadian GEM numerical models (Ventusky website of the InMeteo meteorological company), as well as four-times-daily barotropic topography charts from the Wetter3.de website for 24–28 November 2023. Particular attention was paid to wind and wave characteristics, and the water-air temperature difference as a factor influencing the development of cyclonic circulation and the intensification of wind waves [5, 6].

Archival data from aerological (radiosonde) soundings of the atmosphere at the meteorological stations of Istanbul (Kartal), Turkey, and Heraklion Airport, Greece, from the University of Wyoming website [7] for 20–28 November 2023 were used.

Atmospheric circulation, wave, and wind characteristics for 24–28 November 2023 were examined in detail.

Results and discussion

On 25 November 2023, at 00:00 UTC, a latitudinally oriented polar front with active cyclonic activity was located over the Mediterranean–Black Sea region. This activity was represented by a wave crest over the Kerch Strait, a cyclone with a central pressure of 990 hPa west of Istanbul, and a cyclone (central pressure of 990 hPa) over the northern part of the Aegean Sea, which was the last in a series of frontal cyclones (Fig. 1, *a*).

The maintenance of cyclonic activity over the warm waters of the Aegean Sea was facilitated by favorable thermodynamic factors: the leading part of a deep baric trough, an intense upper-level frontal zone, divergence of upper-level flows, and the temperature contrast between air masses in the 500–1000 hPa layer (Fig. 1, *b*). The nature of the baric field also played a role, in that the rear isobars of the final cyclone were connected with cyclones located further north, over central Russia.

Thus, the nature of the baric field indicated the possible development of an active large-scale process in the rear part of the Aegean cyclone. Most of the Black Sea was in the warm sector, resulting in relatively high temperatures and southwesterly winds. The average monthly sea surface temperature over the sea area in November 2023 was 16.5 °C, which corresponds to a positive anomaly of about 2.5 °C relative to the November climatic values for the period 1950–2023 and a deviation from the modern warming trend of about 1 °C [21].

Twenty-four hours later, on 26 November at 00:00 UTC (Fig. 1, *a*), the cyclone, moving at a speed of about 30 km/h in a northeastward direction, shifted to the southwestern coast of the Black Sea; its center was located almost over Istanbul. Atmospheric (radiosonde) sounding of the atmosphere at this point clearly reflects changes in temperature, humidity, and atmospheric stratification during the passage of the cyclonic eddy [8] (Fig. 2).

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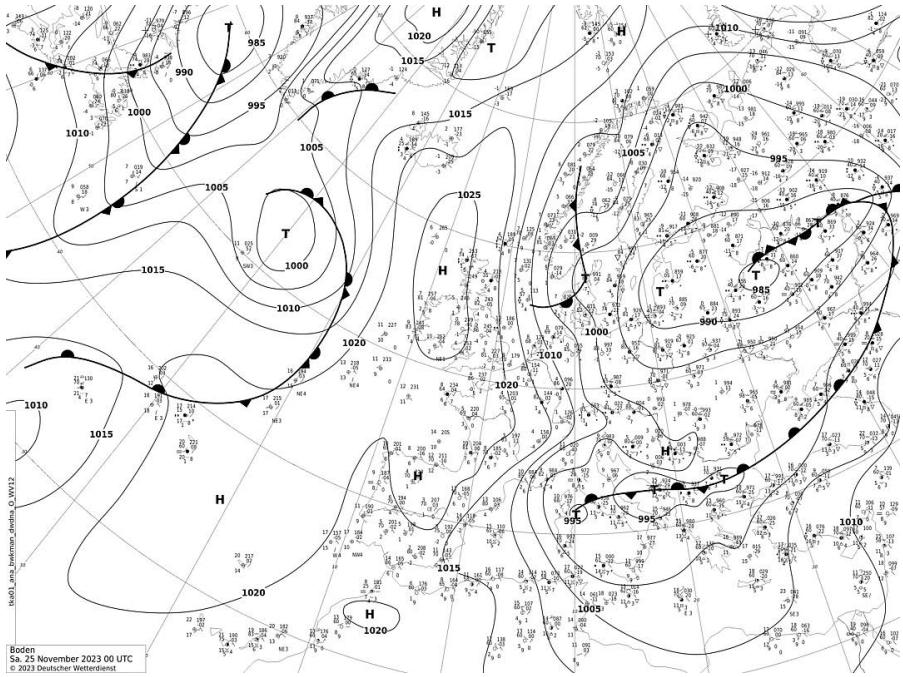
[5] Ventusky. *Weather Forecast, Radar, and Wind Maps*. [online] Available at: https://www.ventusky.com [Accessed: 22 March 2025].

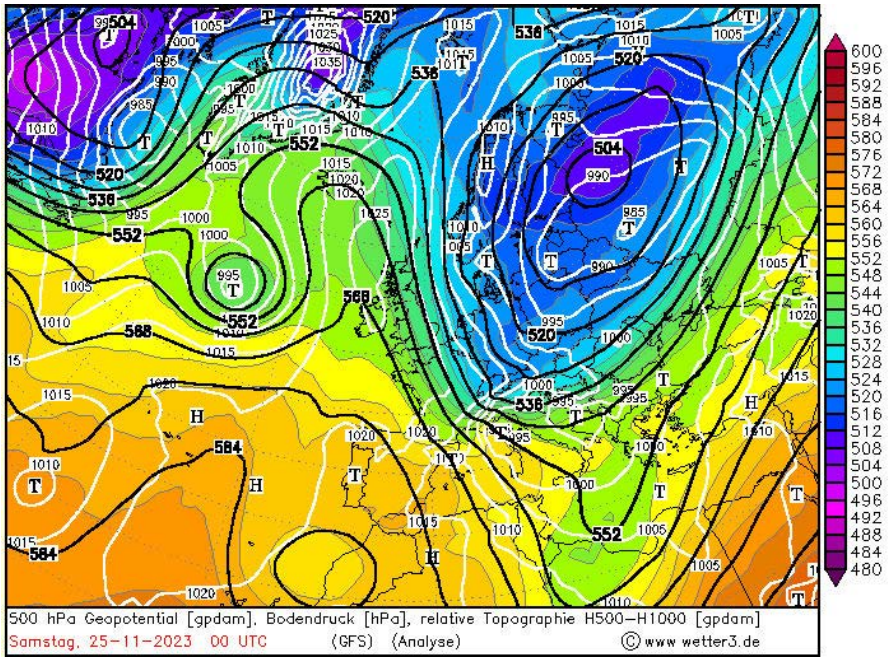
[6] Wetter3. *Die Ganze Welt in Wetterkarten*. [online] Available at: https://www.wetter3.de [Accessed: 22 March 2025].

[7] University of Wyoming. *Atmospheric Science Radiosonde Archive*. [online] Available at: https://weather.uwyo.edu/upperair/sounding.shtml [Accessed: 22 March 2025].

[8] National Centers for Environmental Information. *North Atlantic Oscillation (NAO)*. [online] Available at: https://www.ncei.noaa.gov/access/monitoring/nao/ [Accessed: 05 June 2025].

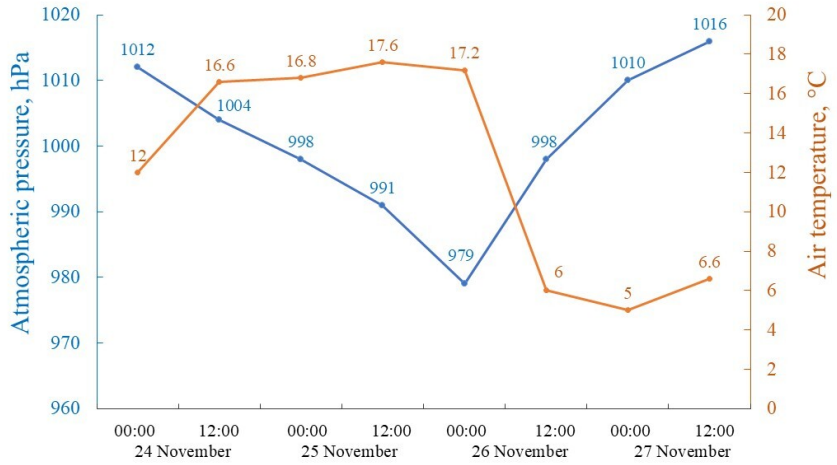


a



b

F i g. 1. Surface weather map [6] for 25 November 2023, 00:00 UTC (*a*); 500/1000 hPa relative topography map [6] for 24 November 2023, 00:00 UTC (*b*)



F i g. 2. Atmospheric pressure and air temperature from aerological radiosonde data obtained at the Istanbul meteorological station, 24–27 November 2023

The pressure at the eddy center dropped to 975 hPa, the thickness of the atmospheric layer with positive convective available potential energy instability was about 300 hPa, and the atmospheric moisture content reached 24.4 mm (indicating a moist air mass). Based on the atmospheric radiosonde data from the University of Wyoming website [7], various indices were calculated (Table 1) to estimate atmospheric stability.

T a b l e 1

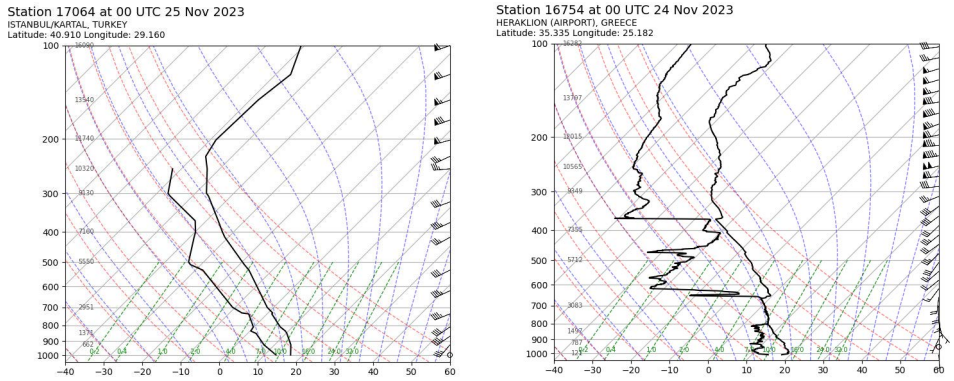
Indices for assessing atmospheric stability [7]

Index	24.11.2023		25.11.2023		26.11.2023	
	00:00 UTC	12:00 UTC	00:00 UTC	12:00 UTC	00:00 UTC	12:00 UTC
SWEAT index	141.99	171.99	264.13	197.29	402.83	142.00
K-index	20.30	23.10	23.30	26.00	33.20	18.00
Vertical totals index	22.30	25.10	30.10	28.50	30.30	27.00
Total totals index	42.60	46.40	52.20	48.00	53.60	51.60
Convective inhibition	0.00	−75.39	−151.13	−112.41	−402.73	0.00
CINS using virtual temperature	0.00	−65.60	−123.06	−92.06	−405.84	−0.52

N o t e: strong convection is highlighted in red, moderate convection – in blue.

Precisely on 24–26 November, the index values indicated atmospheric instability, reflecting the degree of convection and the probability of convective cloud formation with heavy showers, thunderstorms, and even tornadoes (see the cell highlighted in gray in Table 1).

A jet stream with a significant vertical wind shear was recorded over the cyclonic eddy: the maximum speed in the upper troposphere near Istanbul reached 41–48 m/s (Fig. 3, *a*), while near Heraklion Airport it was 50 m/s (Fig. 3, *b*).



a *b*

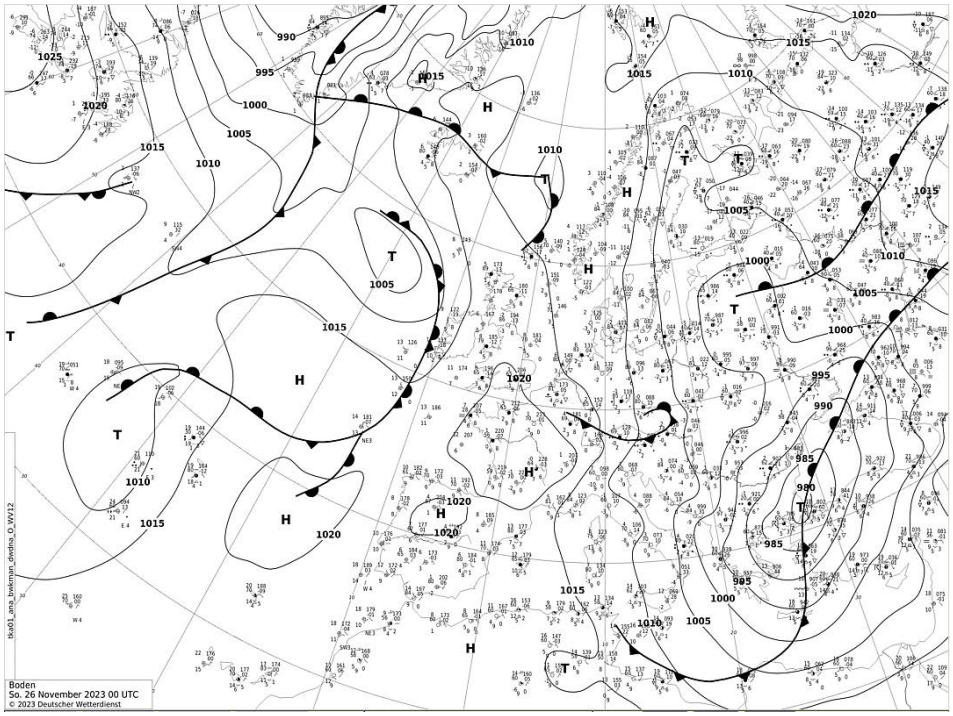
F i g. 3. Aerological diagram [7]: Istanbul (*a*); Heraklion (*b*)

The jet stream proximity created conditions in which the cyclone received additional kinetic energy. Furthermore, the direction of the southwestern wind at the surface and at upper levels coincided, contributing to the intensification of wind over the marine area.

In the following days, the cyclone moved over the Black Sea at a speed of about 60 km/h, then slowed down somewhat upon reaching the continent. By 27 November at 00:00 UTC, the pressure at its center reached 979 hPa.

Fig. 4, *b* shows the trajectory of the cyclone's movement for 25–27 November from the time of formation and the appearance of the first closed isobar on the surface map on 25 November over the Aegean Sea until its exit on 27 November east of the Dnieper River.

Overall, the cyclone, upon reaching the Black Sea, was a deep extratropical one with a clearly defined center, morphologically similar to a tropical cyclone. On the first day, it deepened by 25 hPa, which classifies it as an explosively developing cyclone. Such cyclones are characterized by high translational speed, rapid deepening, and transformation into storm cyclones [11, 12]. Similar "southern" cyclones, when reaching the sea area, gain the opportunity for unimpeded acceleration over the sea surface. Under conditions of baroclinic instability, characterized by a vertical wind shear and an inter-latitudinal temperature gradient, cyclones acquire significant acceleration. Accordingly, the significant pressure gradient in the area of the deep cyclone caused the emergence of strong (at least 15 m/s) and hurricane-force (30–40 m/s) winds. Thus, on the night of 26 November, upon reaching the southern coast of the Black Sea, the maximum speeds of the west-southwest (WSW) wind exceeded 30–40 m/s.



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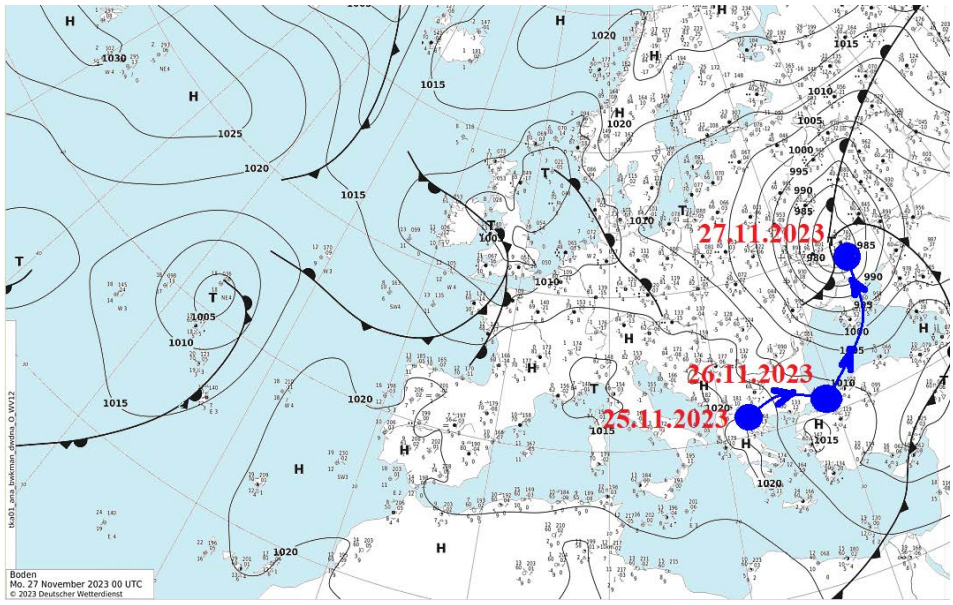


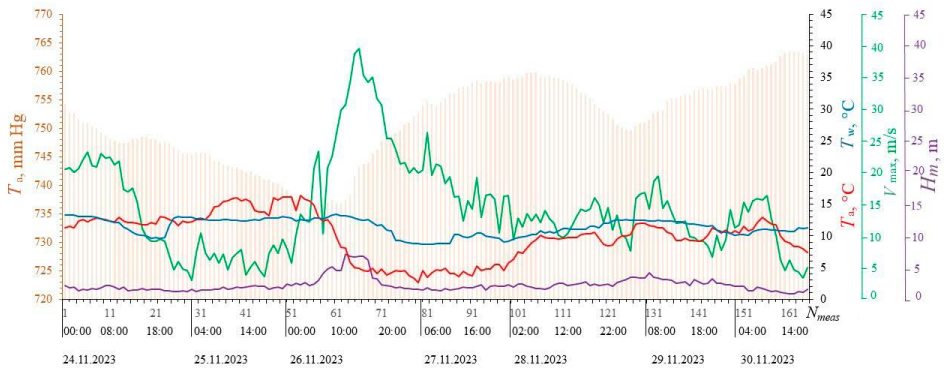
b

F i g. 4. Surface weather map for 26 November 2023, 00:00 UTC (*a*); trajectory of cyclone movement (blue circles and line) for 25–27 November 2023, overlaid on the surface weather map for 27 November 2023, 00:00 UTC (*b*)

When in the first half of 26 November the cyclone's center reached the Crimean Peninsula, the wind direction changed to a rear-sector one (northwest), leading to powerful advection of cold Arctic air and a sharp drop in air temperature − in Istanbul, it cooled by 11 °C to 6 °C within half a day (see Fig. 2). This process is conditioned by the meridional orientation of the rear isobars and the negative phase of the North Atlantic Oscillation (NAO) index [8], which was −0.3 in November 2023. The highest wind speeds were observed in the central and western parts, and in the warm sector of the cyclone. In the western part of the basin, an area of storm waves up to 3 m high formed, and by 13:00 UTC, as the storm moved east and wave height and period grew, wave height reached 5 m [22].

Almost the entire coast of the Crimean Peninsula was hit by the elements: wind speeds reached 40 m/s, up to 33 mm of precipitation fell in a day, the Alushta – Feodosia highway was flooded, and sea wave heights reached 6–7 m. In Simferopol, the wind knocked down about 80 trees, hundreds of power lines and gas pipelines were damaged, dozens of people were injured, and there were fatalities [9, 10]. The powerful storm cyclonic system brought hurricane-force winds, heavy rains, and local flooding to coastal areas. The next day, 27 November, the cyclone left the water area and continued moving north, gradually filling.

The combination of hardware and software in the information collection and processing system at the platform of the Black Sea hydrophysical subsatellite polygon of MHI made it possible to track the development of storm processes in near real time [13, 19]. The dynamics of hydrometeorological parameters measured during the passage of the storm are given in Fig. 5.



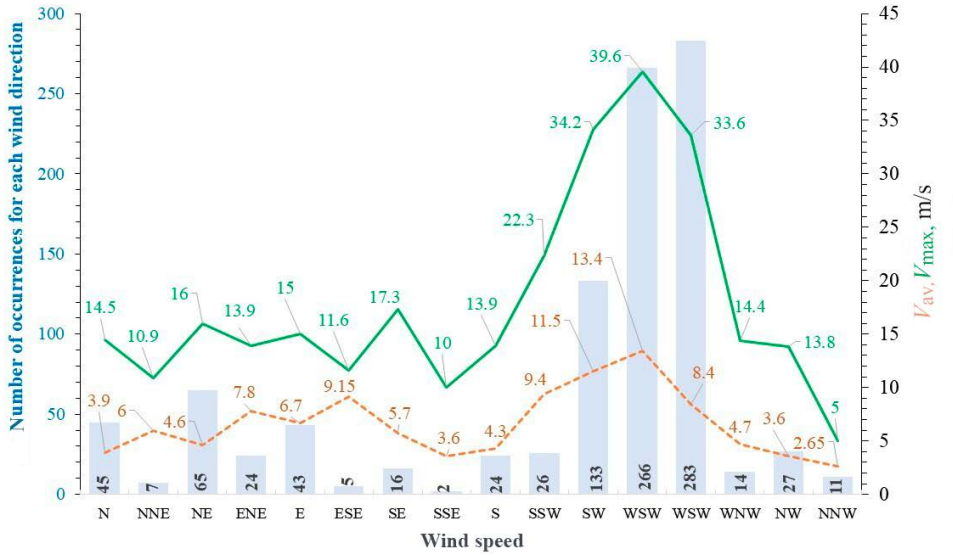
F i g. 5. Dynamics of maximum wind speed V_{max}, wave height H_m, atmospheric pressure Pa, and air T_a and water Tw temperature for 24–30 November 2023 (N_{meas} – measurement sequence number)

[9] Grobman, E., 2023. [A Severe Storm Swept across Southern Russia]. *Vedomosti*, 28 November, 2023. [online] Available at: https://www.vedomosti.ru/society/articles/2023/11/28/1008025-po-yugu-rossii-proshelsya-silneishii-shtorm [Accessed: 10 April 2025] (in Russian).

[10] Ivershin, A., 2023. [The Hurricane in Crimea Began to Subside on November 28, 2023]. *KP.RU*, 28 November, 2023. [online] Available at: https://www.kp.ru/russia/novosti-turizma-v-rossii/uragan-v-krymu-poslednie-novosti-na-28-noyabrya-2023/ [Accessed: 10 April 2025] (in Russian).

The convergence of all parameter curves to their peak values in the same time interval clearly demonstrates the culmination of the storm. The peak impact of the elements on the peninsula occurred in the first half of 26 November, which is confirmed by archival synoptic charts [6] and media reports [9, 10].

The minimum atmospheric pressure, equal to 736.1 mm Hg (981.4 hPa), was recorded at the platform on 26 November at 06:50. The air temperature dropped sharply from 16.5 to 1.5 °C in less than a day, while the water temperature during this period reached a maximum of 13.4 °C (Fig. 5). The maximum wave height recorded near the platform was 7.14 m. The prevailing wind directions at the moment the storm passed over the platform were west (W), west-southwest (WSW), and southwest (SW) with maximum wind speeds of 33.6, 39.6, and 34.2 m/s, respectively (Fig. 6).



F i g. 6. Repeatability of wind direction, average V_{av} and maximum V_{max} wind speeds recorded at 10-min intervals at the oceanographic platform during 24–30 November 2023

The main factor in wind-wave formation is the surface wind field. Visualization of wind wave parameters, performed earlier [23], allows for assessing the maritime situation and forecasting the state of the Black Sea basin. However, in practice, wave forecasts are usually based on wind speed and direction forecasts. The reliability of this method is limited, as wind measurements are made at a network of meteorological stations and posts located on land. On vessels, measurements are made under very difficult conditions, often with a manual anemometer. Instrumental measurements performed at the platform under storm conditions proved to be unique and highly informative, clearly reflecting the synoptic conditions of storm development (see Fig. 5).

Table 2 presents data obtained at coastal meteorological stations in Crimea and at the platform. Comparative analysis of these materials showed that the maximum and average wind speeds recorded at the platform significantly exceed the values obtained at meteorological stations. In the absence of such obstacles to wind as buildings, vegetation, and terrain features, on the open sea surface the average and maximum wind speeds exceed those measured on land by a factor of two or more.

Table 2

Hydrometeorological parameters at the coastal meteorological stations in Crimea and at the platform for November 24–28, 2023

Parameter	Platform	Yalta	Sevastopol	Kerch	Feodosiya	Evpatoriya	Alushta	Chersonesos lighthouse
T_{av}, °C	9.9	8.8	9.8	7.8	9.3	9.1	9	10.5
$T_{a\,max}$, °C	16.9	14.2	17.3	15.8	16.2	14.2	14.9	16.5
$T_{a\,min}$, °C	1.5	2.4	3	−1.4	1.2	1.0	2.0	3.8
T_w, °C	11.4	11.9	–	8.8	12.5	11	13.4	–
Po, mm Hg	749	744.2	750	748.4	745.6	748.2	744	750.2
Po$_{max}$, mm Hg	759.8	754	760	756.7	756	759	754	760.3
Po$_{min}$, mm Hg	736.1	732	736	734.1	733	733	731	736.2
DD (points)	W	W	SW	S	SW	W	NW	SW
V_{av}, m/s	13.6	2.8	8.9	6.4	4.1	5.3	3.2	7.6
V_{max}, m/s	39.6	7	23	15	10	13	13	28
$H_{m\,max}$, m	7.14	–	–	–	–	–	–	5.7

N o t e: $T_{a\,av}$ ($T_{a\,max}$, $T_{a\,min}$) is average (maximum and minimum) air temperature; T_w is water temperature; Po (Po$_{max}$, Po$_{min}$) is average (maximum and minimum) station-level atmospheric pressure; *DD* is wind direction; V_{av} and V_{max} are average and maximum wind speeds; $H_{m\,max}$ is maximum wave height.

Regarding data on wave height and other wave characteristics, continuous instrumental measurements in this region are carried out only at the platform. At the Chersonesos lighthouse hydrometeorological station, measurements are also carried out, but by a standard semi-instrumental method – through visual observations using a graduated pole installed in the sea. Therefore, measurement data from the platform can only be compared with satellite data obtained earlier [7].

The Crimean Peninsula shields waves from western and northwestern directions, which leads to a reduction in extreme wave heights by half or more in the extensive coastal water area from the southern tip of the peninsula to Cape Chauda. These data are consistent with the results of the analysis of the November

2023 storm over the Black Sea basin, when maximum wave heights and periods exceeded 9 m and 13 s, respectively [22].

The accuracy of the studied characteristics depends on the method of their acquisition: visual or instrumental. Nevertheless, instrumental measurements are considered the standard, as they are used for calibrating all other methods [11]. Therefore, the data obtained at the platform are of significant value for solving various scientific and applied problems.

Conclusion

Based on the analysis of the circulation conditions for the formation and development of the storm in November 2023 and the study of instrumental measurement data from hydrometeorological monitoring at the stationary oceanographic platform of the Black Sea hydrophysical subsatellite polygon of MHI during the storm passage, the following conclusions are drawn.

The cyclone observed on 25–27 November 2023 is an extratropical cyclone, similar in its development to explosive cyclogenesis, as it deepened by 25 hPa on the first day and was characterized by a high translational speed.

Its formation was influenced by favorable thermodynamic factors:

– the leading part of a deep baric trough;

– an intense upper-level frontal zone;

– divergence of upper-level flows;

– a strong 500–1000 hPa temperature contrast between air masses.

The following influenced the intensification of the cyclone and the formation of storm-force wind speeds and extreme waves:

– a jet stream with significant vertical wind shear over the cyclonic vortex, supplying the cyclone with kinetic energy;

– an inter-latitudinal temperature gradient, caused by powerful advection of cold Arctic air onto the anomalously warm sea surface;

– a significant pressure gradient;

– coincidence of the southwestern wind direction near the ground and at altitude;

– unimpeded acceleration of airflows upon reaching the sea surface.

The meridional orientation of the rear isobars and the negative phase of the North Atlantic Oscillation conditioned the meridional transport of cold Arctic air masses.

Climate warming and rising Black Sea temperatures contribute to the intensification of evaporation from the ocean surface, which, in turn, can lead to an increase in the frequency of extreme cyclones with destructive consequences.

The unique data obtained under extreme storm conditions at the Black Sea hydrophysical subsatellite polygon of MHI are of high scientific value. They are required for verification and improvement of predictive models, for engineering

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calculations during the construction of structures in the coastal zone of Crimea, and for refining the results of calculations performed by other methods.

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Yuri N. Toloknov – development of the instrument assembly scheme, component installation, sensor calibration, installation and securing of the device on the platform, data collection (field measurements)

Alexey I. Korovushkin – assembly and installation of the experimental instrument for data recording, installation of equipment on the measurement platform, data collection, editing and critical revision of the manuscript

Lyubov N. Vasilevskaya – formulation of aims and objectives, responsibility for data integrity and reliability of results, literature search, analysis of atmospheric processes, interpretation of results, editing and critical revision of the manuscript

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