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Original article

Synoptic Water Temperature Variations in Martynova Bay (Black Sea) in 2000–2020 and the Factors Defining Them

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Abstract

The paper analyses a sample of daily coastal observations to reveal patterns of water temperature temporal variability in Martynova Bay for 2000–2020. In the time course of water temperature, a response (in the form of positive and negative extremes) to synoptic processes in the atmosphere and sea was tracked. In the cold season, three groups of such extrema were identified. These are clearly expressed maximums in November determined by the transfer of warm air mass from the Transcaucasia to the Black Sea; minimums in December–February due to Arctic invasions; and less significant highs in February–March caused by the foehn wind effect. In the warm half of the year, two groups of extremes were identified in the time course of water temperature. These are maxima caused by overheated air masses, which spread to the Black Sea from the Sal steppes in June–August, and minimums in June–September associated with the influence of the Black Sea upwelling. It is shown that in the bays of the northern coast of the Heraclean Peninsula, fluctuations in water temperature caused by surge winds were insignificant. Their range did not exceed 1 °C, and the duration of the cycle, as a rule, was no more than one day.

Keywords: water temperature, anomalies, Arctic invasion, foehn, upwelling, surge phenomena, bays of Sevastopol, Crimea

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Синоптические вариации температуры воды в Мартыновой бухте (Черное море) в 2000–2020 годы и определявшие их факторы

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Аннотация

На основе анализа выборки ежесуточных прибрежных наблюдений раскрыты закономерности временной изменчивости температуры воды в Мартыновой бухте с 2000 по 2020 г. Во временном ходе температуры воды отслежен отклик (в виде положительных и отрицательных экстремумов) на синоптические процессы в атмосфере и море. В холодное время года выявлено три группы таких экстремумов: отчетливо выраженные максимумы в ноябре, определявшиеся выносом на Черное море теплой воздушной массы из Закавказья; минимумы в декабре – феврале, обусловленные арктическими вторжениями; и менее значимые максимумы в феврале – марте как следствие фёнового эффекта. В теплое полугодие во временном ходе температуры воды выделены две группы экстремумов: максимумы, обусловленные перегретыми воздушными массами, которые распространялись на Черное море из района Сальских степей в июне – августе, и минимумы в июне – сентябре, связанные с влиянием черноморского апвеллинга. Показано, что в бухтах северного берега Гераклейского полуострова колебания температуры воды, вызываемые сгонно-нагонными ветрами, незначительны. Их размах не превышает 1 °C, а длительность цикла, как правило, не более 1 сут.

Ключевые слова: температура воды, аномалии, арктическое вторжение, фён, апвеллинг, сгонно-нагонные явления, бухты Севастополя, Крым

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Introduction

Martynova Bay is located in the south-west of Sevastopol Bay, at its mouth. Until the 1970s, it was not part of Sevastopol Bay. At present, the bay is separated from the open sea by the southern breakwater. Its maximum depth is 17 m at the end of the breakwater. The meridional length and width at the entrance is about 480 m. Water exchange with the open sea is limited. Irrespective of wind direction and strength, smooth waves prevail in Martynova Bay. In the open part of the sea behind the southern breakwater, there is an oyster and mussel farm of LLC NIO Mariculture. In this water area, Institute of Biology of the Southern Seas (IBSS) regularly monitors water temperature (Fig. 1).

Time series of observations of aquatic environment parameters in coastal waters are extremely important for the improvement of knowledge in various fields of the marine science. The combination of coastal temporal observations with observations in open waters, which, as a rule, are presented as spatial distributions, allows revealing the regularities of temporal variability of the fields of oceanological variables in the oceans and seas [1, 2].

The results of the analysis of observations in the bay under study has applied significance because of their representativeness both for the entire Black Sea area and for the sea area off South-West Crimea, including bays and open areas of the Sevastopol seashore.

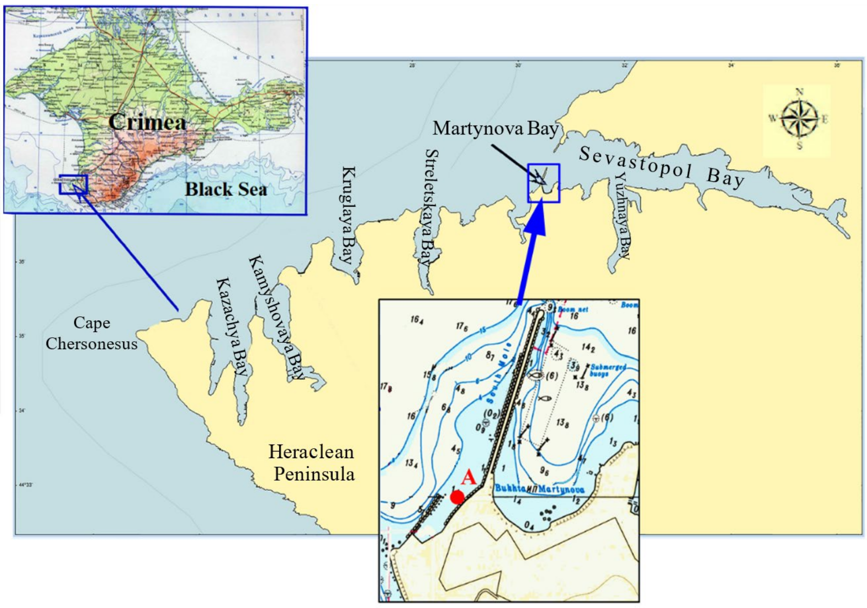


Fig. 1. Geographical position of Martynova Bay (A is the point of water temperature observations)

The aim of the work is to reveal the regularities of synoptic variability of water temperature in Martynova Bay for the time interval from 2000 to 2020 based on the analysis of coastal observations, as well as to identify the factors determining the corresponding types of fluctuations.

Source data and study methods

We analysed a sample of daily (conducted at 12:00 (GMT +3)) coastal water temperature observations from 2000 to 2020, which were taken in Martynova Bay near the oyster and mussel farm of LLC NIO Mariculture (point A in Fig. 1).

Information on the atmospheric synoptic situation in the Azov-Black Sea basin was obtained by analysing synoptic maps from the archive of Wetterzentrale Hydromet Centre (Germany) (URL: http://old.wetterzentrale.de/topkarten/fsreaeur.html).

Synoptic weather data for Sevastopol were taken from the Weather website of the marine meteorological station Chersonesos Lighthouse (URL: http://rp5.am/Погода_на_Херсонесском_маяке).

For ease of analysis, the entire initial set of actual water temperature observations was divided into two parts, referring to cold (November–April) and warm (May–October) half-years. The data was then averaged on a ten-day basis. Further, for each half-year in the coordinate system "current day, current year" and "current ten-day period, current year", temporal temperature sweeps were constructed (Figs. 2, 3), which were used to assess the response of the considered variable to synoptic processes in the atmosphere and in the sea, as well as to local regional processes.

The averaged schemes were calculated to filter out the noise and assess the significance of the extremes detected in the actual time sweeps. Only significant extremes that appeared in the mean ten-day sweeps were considered in detail.

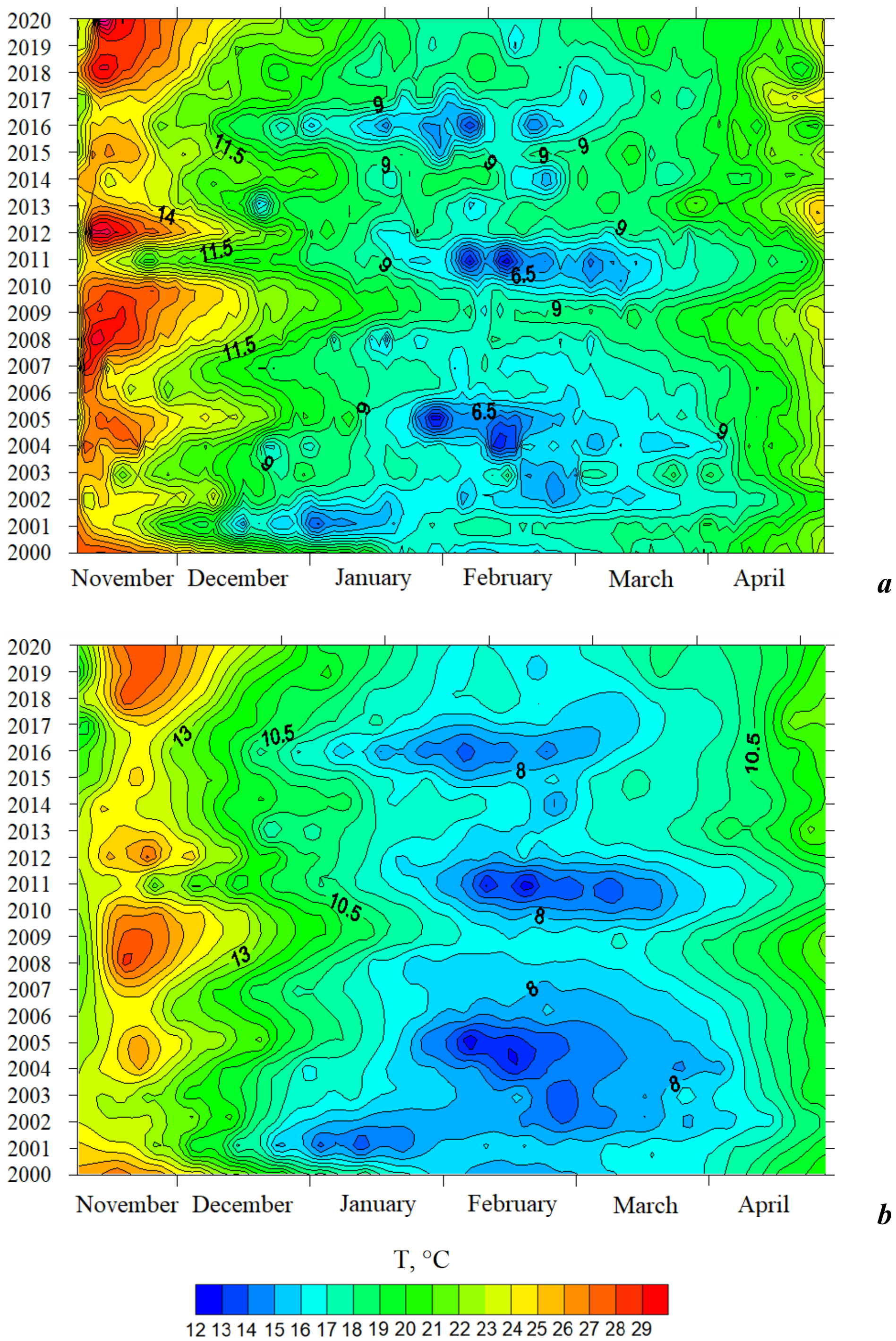
Discussion of results

The temporal sweeps of both the actual and mean ten-day water temperature show positive and negative local extremes indicating processes of different time scales in the atmosphere and sea that determined the variability of the considered parameter of the aquatic environment (Figs. 2, 3).

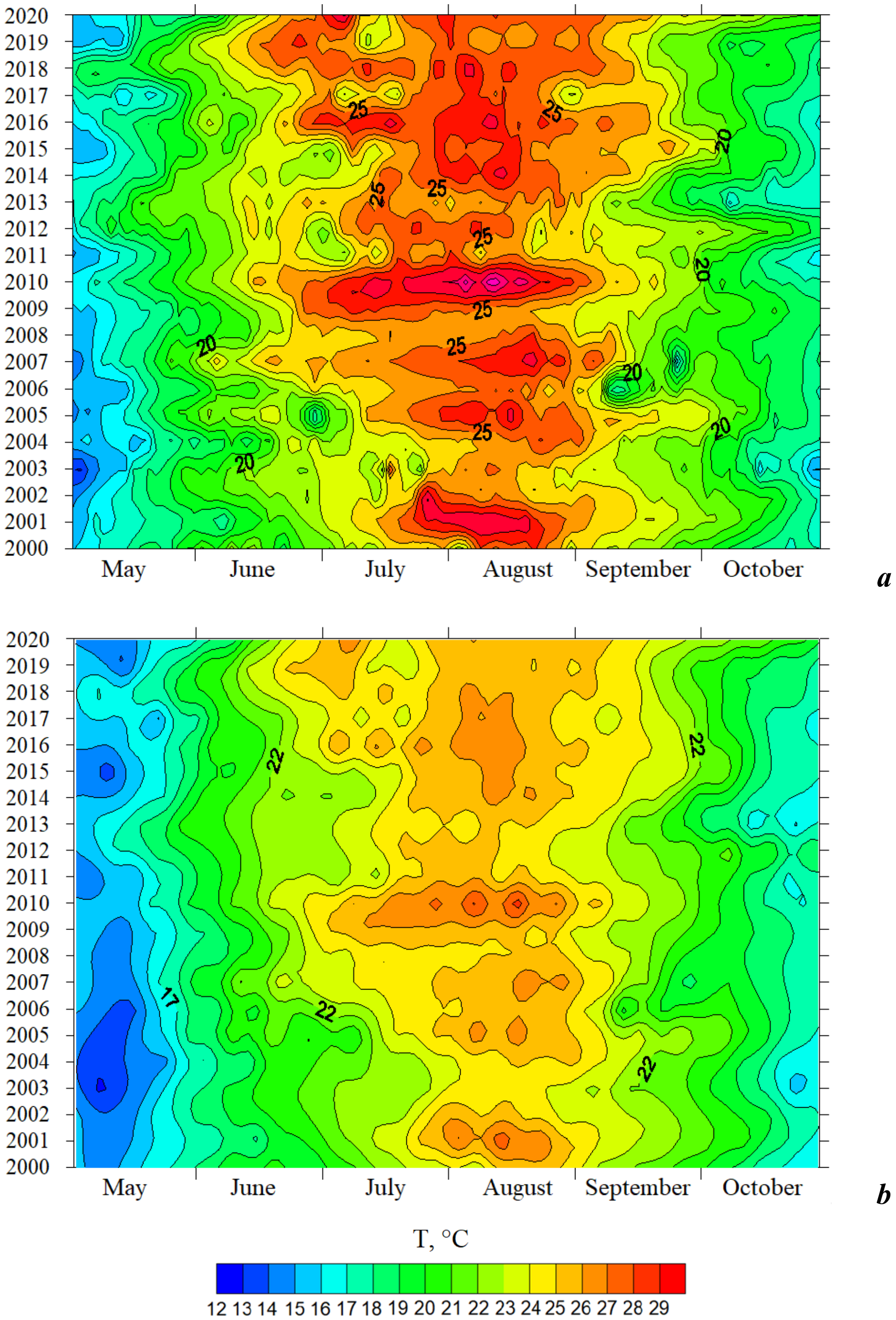
In the cold season, three groups of such extremes were identified: pronounced maxima in November, minima in December–February and less significant maxima in February–March.

In November, in the temporal sweep of the actual water temperature, the maximum was observed in 15 cases (years) out of 21, whereas in the sweep of mean ten-day temperature, this extreme was quite clearly manifested only 12 times: in 2000, 2004, 2005, 2007–2010, 2012, 2015, 2018–2020 (Fig. 2).

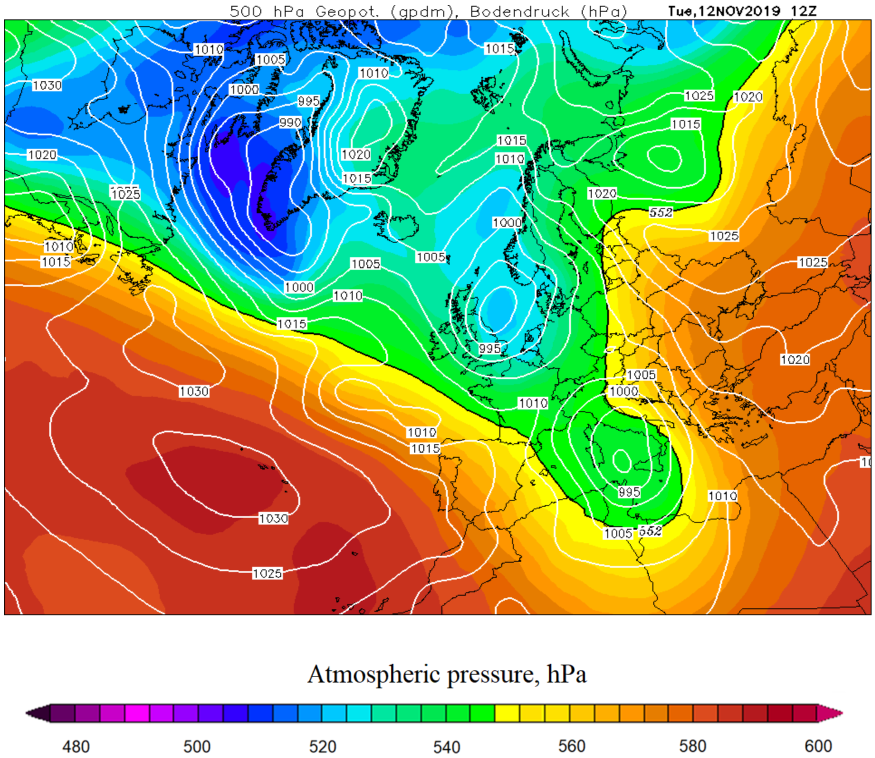
In these years, the atmospheric synoptic situation was analysed for November using archived synoptic maps, which showed the following. The weather over the Black Sea was determined by the influence of the southern southwestern periphery of the Siberian High (Transcaucasia), which determined the heat transfer from the warmed continent (Fig. 4).



F i g . 2 . Time variations of water temperature in Martynova Bay during the cold half of the year for 2000–2020: daily (*a*), average ten-day (*b*)



F i g . 3 . Time variations of water temperature in Martynova Bay during the warm half of the year for 2000–2020: daily (*a*), average ten-day (*b*)



F i g . 4 . Synoptic situation illustrating the transfer of heat from Transcaucasia to the Black Sea in the circulation system of the southern south-western periphery of the Siberian High, map on 12 November 2019, 12:00 GMT

During this atmospheric natural anticyclonic synoptic period lasting from 1 to 2 ten-day periods, the air in Sevastopol warmed up to 15–20°C and the water temperature in Martynova Bay increased by 0.6–1.7 °C against seasonal cooling and reached 15.1–17.4°C.

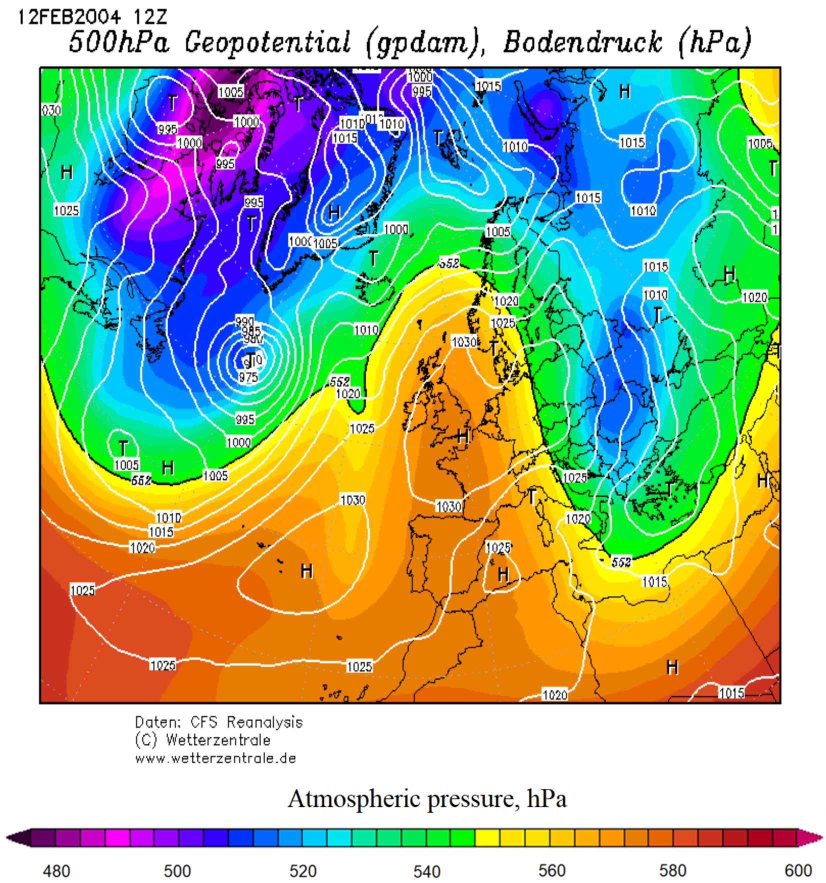
In similar situations, there is a noticeable warming of shallow top parts of Sevastopol bays, where vertical stratification of the temperature field also forms. At the boundary with the central parts of the bays, pronounced frontal temperature sections appear. In the morning, at the maximum difference of water and air temperature (up to 10 °C), steam fog can be observed over the top parts of the bays.

Another significant atmospheric natural synoptic process that contributed to the extreme cooling of coastal waters during the cold half-year is determined by the Arctic invasions of cold air masses. The synoptic situation typical of the Arctic invasion was determined by the rear part of a trough meridionally orientated from the Kara Sea to the Black Sea (Fig. 5). The most powerful inflows of Arctic cold observed in December–February were accompanied by a significant (down to –17...–15 °C) drop in air temperature in Sevastopol, and the water temperature in Martynova Bay dropped to minimum values (4–6 °C).

In the time course of the actual water temperature, local minima associated with Arctic invasions were observed in 9 cases (years) out of 21 (see Fig. 2, *a*). In the sweep of the mean ten-day temperature for the cold half-year, the most significant extremes appeared 8 times: in 2001, 2003–2005, 2011, 2014–2016 (Fig. 2, *b*).

The insignificant increase in water temperature observed in February–March was due to a local meteorological phenomenon – the foehn effect.

In Sevastopol, foehn is usually observed in February with southeastern transfer in the atmosphere. In this case, a dry warm wind from the spurs of the Crimean



F i g . 5 . Synoptic situation during the polar invasion of the Black Sea, map on 12 February 2004, 12:00 GMT

Mountains contributes to the inflow of warm air and setting in of dry clear weather with air temperatures in the Sevastopol region up to 20 °C and higher.

Foehn, as a local phenomenon lasting up to ten days, does not lead to a fairly significant increase in water temperature. According to the analysed data, the water temperature increase caused by the foehn effect is generally no more than 0.5 °C; in some cases, it can be 0.6–0.8 °C.

Foehns are a rather frequently observed phenomenon at the end of winter. In the field of actual water temperature, they were recorded almost annually except for four years with the lowest winter temperature: 2004, 2005, 2011, 2016 (Fig. 2, *a*).

The most intense foehns, which caused water warming in Martynova Bay by 0.6–0.8 °C, are quite rare and were observed only in 2015 and 2018–2020 (Fig. 2, *b*).

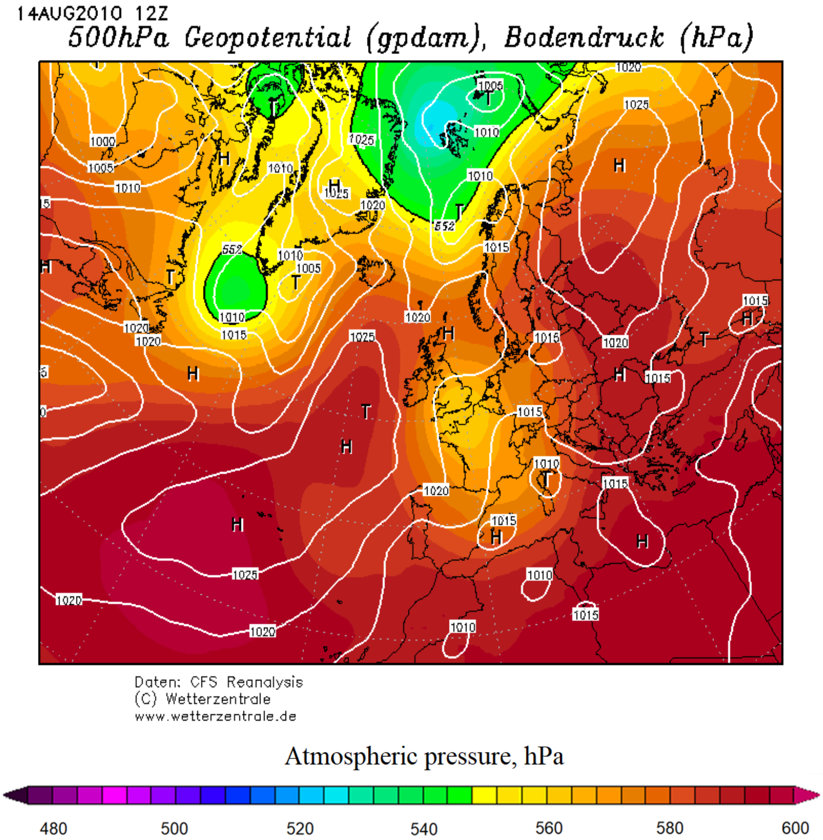
For the Sevastopol region, the foehn effect is extremely important in terms of ecology. A sharp increase in air temperature at the end of winter causes intensive snow melting in the catchments of Crimean rivers, which are traditionally considered polluted [3]. The water flow rate in the rivers almost instantly increases to values that are by an order of magnitude higher than average. At the same time, a huge number of pollutants enters the bays and open areas of the sea. These phenomena for the Balaklava Bay area are considered in detail in the book [4].

For the warm season, the time course of water temperature revealed two groups of extremes: distinct maxima in June–August and minima in June–September (see Fig. 3).

High actual water temperatures (26–28 °C) were observed in 2005, 2007, 2012, 2014–2017. The water in the analysed bay warmed up to the maximum (up to 28–30°C) in 2001 and 2010 (Fig. 3, a). In 2001, 2010, 2014–2017, the temperature maxima (27–28°C) were manifested in the mean ten-day sweep (Fig. 3, *b*).

The above cases were caused by extremely high air temperatures (up to 33–37 °C). In July–August, overheated air masses spread to the Azov–Black Sea basin by the northeastern wind from the Sal steppes, where the average summer air temperature reaches 35–45 °C [5]. At the same time, the synoptic situation was determined by the eastern southeastern periphery of the Azores High (Fig. 6).

In June–September, cyclic changes in water temperature were observed on the time scale from several days to 2–3 ten-day periods. These changes, accompanied by a significant decrease in water temperature, were caused by the coastal Black Sea upwelling. The coastal Black Sea upwelling, the most significant mechanism providing the water exchange between the shelf and deep-sea zones, is relatively well studied for the deep-water areas around the perimeter of the Black Sea. The nature of this phenomenon is attributed to the influence of atmospheric circulation over the Azov–Black Sea basin [6–8].



F i g . 6 . Synoptic situation in conditions of superheated air outflow to the Black Sea from the Sal steppes, map on 14 August 2010, 12:00 GMT

The features of the coastal Black Sea upwelling in Martynova Bay and on the Sevastopol seashore were analysed in the article [9] and are briefly listed below. The most powerful upwelling was observed in June 2001, June–July 2005, September 2006, September 2007, July–August 2011, July–August 2013, July–August 2015, July and September 2017, July 2019, July 2020 (Fig. 5). A total of 42 upwelling events with a temperature range of 2–7°C were recorded from 2000 to 2020. Their duration varied from 4 to 32 days.

The most frequent upwellings in Martynova Bay were recorded in June–July. The most intensive ones were recorded in June. The same pattern is typical of upwelling in the area of the depth gradient off the western coast of Crimea [7]. Upwellings with a cycle duration of 4–8 days had the highest frequency of occurrence (31 %). Upwellings with a cycle of 20–32 days were observed much less frequently. Their total frequency of occurrence was 11 %.

The typical properties of the hydrological regime of Sevastopol bays include surge phenomena [10]. The analysed dataset does not allow us to consider such phenomena due to the discreteness of observations.

Observations of water temperature, which were conducted in the Sevastopol marine fishing port in Kamyshovaya Bay and on the beach in Kruglaya Bay (Omega) with a discreteness of 6 h, showed that water temperature fluctuations caused by water surge winds were insignificant. Their magnitude did not exceed 1 °C and the cycle duration was generally not more than 1 day.

This effect can be explained by the morphometric features and location of the bays on the northern coast of the Heraclean Peninsula as well as by the wind regime of the Sevastopol region. The axial lines of the bays – from Kazachya Bay to Yuzhnaya Bay (see Fig. 1) – are oriented along the meridian, and the bays themselves face northwards with their open parts. The winds of the northern quarter cause an upsurge, while the winds of the southern quarter cause a downsurge.

A special property of the breeze circulation in the Sevastopol region is that the daytime northwesterly breeze as well as the nighttime northeasterly one have a significant northerly component, which often prevails over the gradient wind in the warm season. Therefore, during the warm half of the year, the northern coast of the Heraclean Peninsula with its bays is mainly affected by the upsurge winds. Southern quarter downsurge winds, which cause a decrease in water temperature, are rare. Moreover, they have a very limited acceleration within each of the bays, and the adjacent water area of the Sevastopol seashore has a relatively shallow depth.

The above mentioned allows us to suppose that near the northern shore of the Heraclean Peninsula and in the corresponding bays, the wind-induced water temperature fluctuations are insignificant and their range is not more than 1 °C.

Conclusion

Based on the analysis of a sample of daily coastal observations, the regularities of temporal variability of surface water temperature in Martynova Bay from 2000 to 2020 were considered, and the factors causing this variability were analysed.

In the time course of water temperature, both actual and average ten-day temperature, the response (in the form of positive and negative extremes) to synoptic processes in the atmosphere and in the sea was traced.

During the cold season, three groups of such extrema were identified: distinct maxima in November, minima in December–February and less significant maxima in February–March.

The increase in water temperature in November by 0.6–1.7 °C against a seasonal cooling was determined by the transfer of warm air masses from the Transcaucasia to the Black Sea in the circulation system of the southern south-western periphery of the Siberian maximum. A drop in water temperature to a minimum of 4–6 °C in December–February was provided by Arctic intrusions. The foehns in February–March were accompanied with water warming in Martynova Bay by about 0.5 °C.

During the warm half of the year, two groups of extrema were identified in the time course of water temperature: maxima in June–August and minima in June–September.

Extremely high water temperatures of 28–30 °C were caused by overheated air masses that travelled to the Black Sea from the Sal steppes, where the average summer air temperature reaches 45 °C. The synoptic situation over the Black Sea was determined by the eastern south-eastern periphery of the Azores High.

The cyclical changes of water temperature observed in June–September on a time scale from several days to 2–3 ten-day periods, which were accompanied with its decrease by 2–7 °C, were determined by the Black Sea upwelling.

In the bays of the northern coast of the Heraclean Peninsula, the water temperature fluctuations caused by water surge winds were insignificant. Their magnitude did not exceed 1 °C and the cycle duration was usually not more than 1 day.

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Contribution of the authors:

Pavel D. Lomakin – setting the study goals and objectives, analysis of the obtained results, their interpretation, discussion of the results, writing the article

Mark A. Popov – construction of graphs, maps, qualitative analysis of the results and their interpretation, quantitative processing and description of the study results, discussion of the results, editing the article

All the authors have read and approved the final manuscript.