Original paper

Black Sea Crimean Shelf Zoning by Temporal Variability of Sea Surface Temperature

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Abstract

This study analyzes the daily sea surface temperature from the Copernicus database on a grid with a spatial resolution of 0.05° × 0.05°. It calculates the characteristics of total sea surface temperature variability and seasonal variations across multiple temporal scales. A regional synthesis of these characteristics was performed for four areas along the Black Sea coast of the Crimean Peninsula over the 1991–2020 climate period. Characteristics of seasonal and interannual/decadal variability were evaluated using monthly averages, the main part of the synoptic range was evaluated with 10-day averages and the low-frequency part of the mesoscale band was analysed using daily averages. The results show distinct regional patterns. Karkinit Bay differed significantly from the other regions, exhibiting the largest seasonal range and the highest intensity of variability across all bands during winter. The Western region demonstrated the lowest level of temporal variability in all parameters. The Kerch-Feodosia shelf exhibited the highest variability across all bands in autumn. The Southern Coast of Crimea held an intermediate position in terms of temporal variability characteristics between the Western and Kerch-Feodosia regions. Overall, the shelf zone of the Crimean Peninsula shows enhanced regional contrast in sea surface temperature variability across different temporal scales compared to the open Black Sea. One of the primary drivers of these intense water temperature fluctuations is the occurrence of upwelling and downwelling events, which are linked to the variability of wind fields over the region.

Keywords: Crimean shelf, sea surface temperature, seasonal variability, interannual variability, mesoscale variability, sub-mesoscale variability

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Районирование черноморского шельфа Крыма по характеристикам временной изменчивости температуры воды поверхностного слоя

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Аннотация

На основе массива ежесуточных спутниковых данных *Copernicus* о температуре поверхности моря на сетке с пространственным разрешением 0.05° × 0.05° рассчитаны характеристики общей интенсивности изменчивости температуры поверхности моря и сезонных вариаций температуры на различных временны́х масштабах. Проведено региональное обобщение этих характеристик по четырем районам черноморского побережья Крымского полуострова за климатический период 1991–2020 гг. Характеристики сезонного хода и межгодовой/десятилетней изменчивости оценивались по среднемесячным значениям, основной части синоптического диапазона – по среднедекадным значениям, а низкочастотной части мезомасштабного диапазона – по среднесуточным значениям. Существенно отличается от остальных районов Каркинитский залив, с максимальным размахом сезонного хода и наибольшей интенсивностью во всех диапазонах изменчивости в зимний период. Западный район по всем параметрам имеет самый низкий уровень временно́й изменчивости. Для Керченско-Феодосийского шельфа осенью характерна наибольшая интенсивность изменчивости во всех диапазонах. Южный берег Крыма по характеристикам временно́й изменчивости занимает промежуточное положение между Западным и Керченско-Феодосийским районами. В целом шельфовая зона Крымского полуострова, в сравнении с открытой частью Черного моря, демонстрирует повышенную региональную контрастность в изменчивости поверхностной температуры воды на различных временны́х масштабах. Одной из причин интенсивных колебаний температуры воды являются апвеллинги и даунвеллинги, связанные с изменчивостью полей ветра в рассматриваемом регионе.

Ключевые слова: шельф Крыма, температура поверхности моря, сезонный ход, межгодовая изменчивость, синоптическая изменчивость, мезомасштабная изменчивость

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Introduction

The distribution of sea surface temperature (SST) fluctuation energy across different bands of temporal variability in seas and oceans exhibits distinct regional characteristics. The most distinct regional differences are observed in the characteristics of seasonal variability, which are governed by the seasonal cycle of the sea surface heat balance. The contribution of other bands of temporal variability to the total variance of SST fluctuations has received much less attention than estimates of the mean seasonal cycle. This is due to the requirement for longer SST data series at fixed locations with greater temporal resolution. However, such data are now becoming available thanks to the development of remote sensing methods that use satellite radiometers operating in the infrared and microwave bands as the primary measurement tools.

Comprehensive monographs based primarily on the data analysis from contact observations provide general information on the intensity of sea water temperature variability across different temporal scales in the Black Sea basin [1–4]. With the advent of satellite data, in addition to seasonal variability, interannual fluctuations and long-term SST trends began to be investigated [4–11]. The improvement of spatial and temporal resolution of satellite measurement tools has made it possible to study higher-frequency processes, such as synoptic variability [12] and the diurnal cycle [13–15]. Results of 20 years of research with the use of remote methods confirmed patterns previously identified from contact observations, showing that the intensity of SST variability decreases in the following order of scales: seasonal, interannual, synoptic, mesoscale. The northwestern and northeastern parts of the Black Sea, where both seasonal and interannual SST variability reach their maximum, stand out from other Black Sea parts.

Assessments of the intensity of sea water temperature variability across different temporal bands have been extremely limited for coastal areas. Only a few coastal marine meteorological stations met the necessary requirements for data series, while the reliability and spatial resolution of satellite data near the shore were insufficient. The emergence of digital datasets for individual seas with a resolution of 0.05° enables to perform more detailed assessments of the distribution of fluctuation energy in the coastal zone across various temporal bands.

This study aims to evaluate regional characteristics of overall intensity of SST variability across different temporal scales in coastal and shelf areas of the Crimean shelf, using a satellite dataset with a high spatial resolution.

Materials and methods of research

The study used the Black Sea High Resolution L4 Sea Surface Temperature Reprocessed dataset [1)] from the Copernicus Marine Service. This dataset provides daily night-time SST averages referenced to a depth of 20 cm, with a spatial resolution of 0.05° × 0.05°, from 1 January 1982 to the present day [16]. This product

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[1)] *Black Sea – High Resolution L4 Sea Surface Temperature Reprocessed* [online]. Available at: https://data.marine.copernicus.eu/product/SST_BS_SST_L4_REP_OBSERVATIONS_010_022/description [Accessed: 15 February 2024]. http://doi.org/10.48670/moi-00160 forms part of the global digital SST dataset created for climate research within the following European projects: the ESA Climate Change Initiative and the Copernicus Climate Change Service. It is based on measurements processed from 22 satellite platforms equipped with infrared (AVHRR, ATSR and SLSTR) and microwave (AMSR) radiometers.

Temporal variability in SST was assessed in four areas of the shelf adjacent to the Black Sea coast of Crimea (Fig. 1):

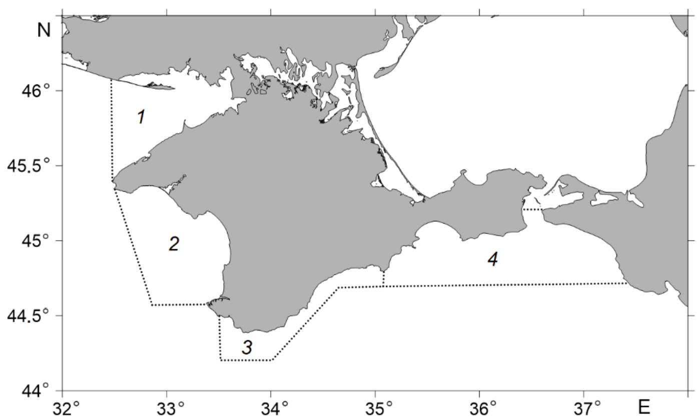
1) Karkinit Bay, which is a constituent part of the extensive northwestern shelf with its own specific hydrological regime;

2) the Western Crimea shelf, which extends from Cape Tarkhankut to Cape Chersonesus and represents a transitional zone between the northwestern shelf and the deep-water part of the Black Sea;

3) the Southern Coast of Crimea, which is characterised by conditions similar to those in the central part of the sea and is directly influenced by the Rim Current (Main Black Sea Current);

4) the Eastern Crimea shelf (Kerch-Feodosia shelf), which extends from Cape Meganom to Anapa and is affected by water exchange with the Sea of Azov, as well as by the Rim Current, which changes direction along the Caucasian coast towards the Crimean Peninsula.

The period from 1991 to 2020 was selected for the calculations as it corresponds to the most recent climate period defined by the World Meteorological Organization (WMO). It is also used as the climate norm when processing this SST dataset.



F i g . 1. Crimean shelf regions division by oceanographic conditions: *1* – Karkinit Bay, *2* – Western Region, *3* – Southern Coast of Crimea, *4* – Kerch-Feodosia Region

Ten-day and monthly averages were calculated for each year from daily data for each grid node. Then, using selected time series, the following variances were calculated:

– variance of daily averages for 365 calendar days;

– variance of 10-day averages for 370 calendar days;

– variance of monthly averages for 12 calendar months.

The overall level of interannual and decadal variability corresponded to the variance of the monthly averages, which were then averaged over the year. The variances of 10-day averages, which characterise synoptic variability to a certain extent (periods ranging from days to a month), were averaged over 12 months and for the full year. Similarly, the variances of daily averages, representing the low-frequency part of the mesoscale band (periods ranging from hours to days), were averaged over 12 months and for the full year. Seasonal variability was assessed from the mean seasonal cycle, namely mean standard deviation and range of the monthly averages, averaged over the selected 30-year period. All resulting mean fields of the calculated temporal variability characteristics were smoothed using a Gaussian filter with a radius of five grid nodes.

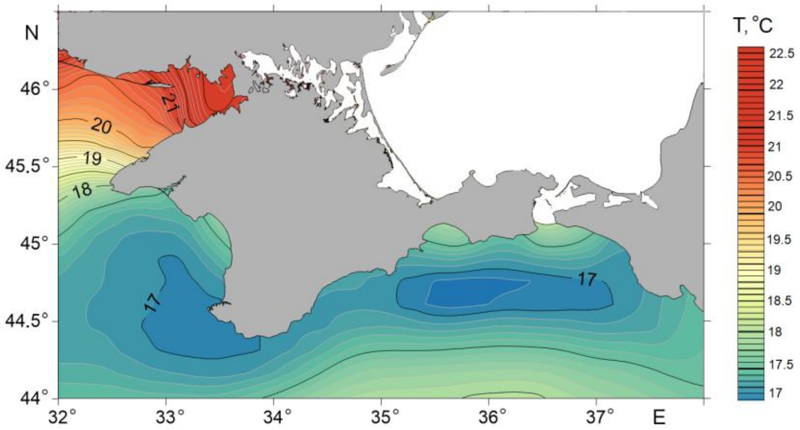
The results were compared with those from other studies [11, 12], which used an earlier version of the Black Sea High Resolution L4 Sea Surface Temperature Reprocessed dataset with a spatial resolution of 0.04° × 0.04° [17]. This dataset was based on AVHRR Pathfinder Version 5.2 (PFV52) and covered the periods 1982–2014 and 1982–2018.

Results and discussion

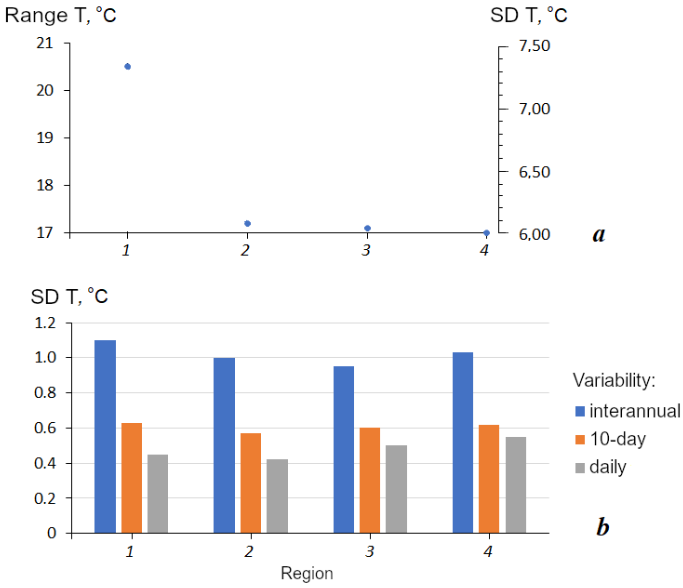
The Black Sea, including its shelf zone, is characterised by a large amplitude of seasonal variability in SST, which exceeds temporal variability on other scales significantly [1–12]. The range of the seasonal cycle increases sharply in the shallow northern areas of the sea that are prone to freezing, reaching a maximum of 22°C in Karkinit Bay (Fig. 2). Conversely, the minimum seasonal range in the Black Sea, which is less than 17°C, is observed in the Kerch-Feodosia region and near the south-western tip of Crimea. This is connected with the warming effect of the Rim Current during winter. Another example of a minimum in the seasonal range in the Black Sea is found off the Sinop Peninsula, where persistent summer upwelling causes the lowest values.

Quantitative values and spatial distribution of mean standard deviation of seasonal variability are in good agreement with the results of [11], despite differences in the averaging period, set of satellite platforms, reference depth of SST and L4 processing algorithms.

As previously noted in [3, 11], the next most intense component after seasonal variability is interannual variability. Its mean standard deviation is much smaller than that of the seasonal component. Using this calculation method, the contribution of lower-frequency fluctuations, such as decadal (10-year) and interdecadal variability, increases as the averaging period increases within this range. The next most significant components, in order of decreasing intensity, are 10-day variability (conditionally synoptic) and daily variability (conditionally mesoscale),



F i g . 2 . Mean season range of the sea surface temperature in the Black Sea near the Crimean coast in 1991–2020



F i g . 3 . Mean standard deviations of seasonal, interannual, 10-day and daily variability of sea surface temperature for four Crimean shelf regions in 1991–2020. Digits stand for region numbers (see Fig.1) which are twice and four times weaker than interannual variability, respectively. The ratio of different SST variability bands exhibits its own regional characteristics in each of the studied areas (Fig. 3).

The spatial distributions of interannual and 10-day variability exhibit a qualitatively similar pattern (Fig. 4). The main difference from the seasonal cycle spatial distribution is the emergence of a new maximum in the Kerch Strait area and the reduction of the zone of maximum values in Karkinit Bay. When considering the higher-frequency part of the spectrum (i. e. daily variability), a minimum appears in the southwestern region (i. e. Kalamita Bay) (Fig. 5).

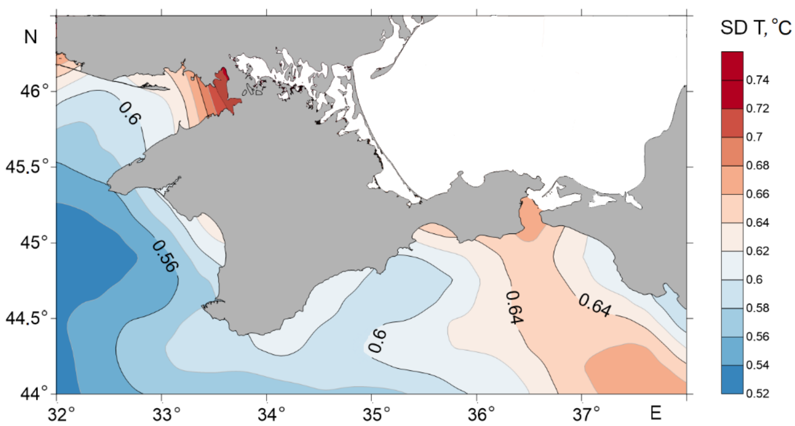


Fig. 4. Mean standard deviation of 10-day variability of sea surface temperature near the Crimean coast in 1991–2020

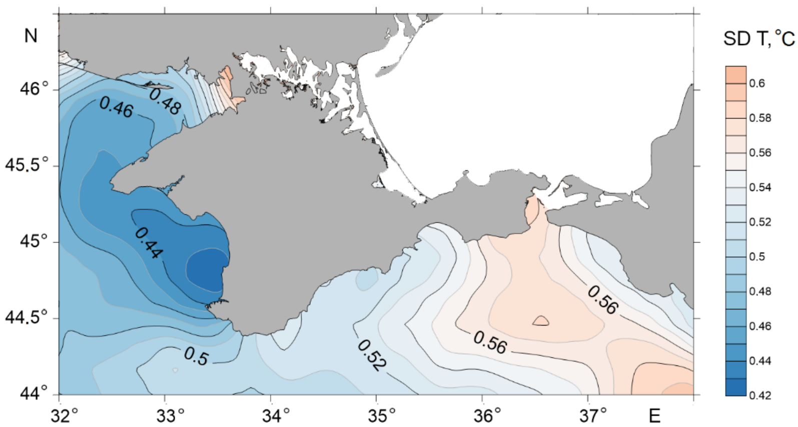


Fig. 5. Mean standard deviation of daily SST variability near the Crimean coast in 1991–2020

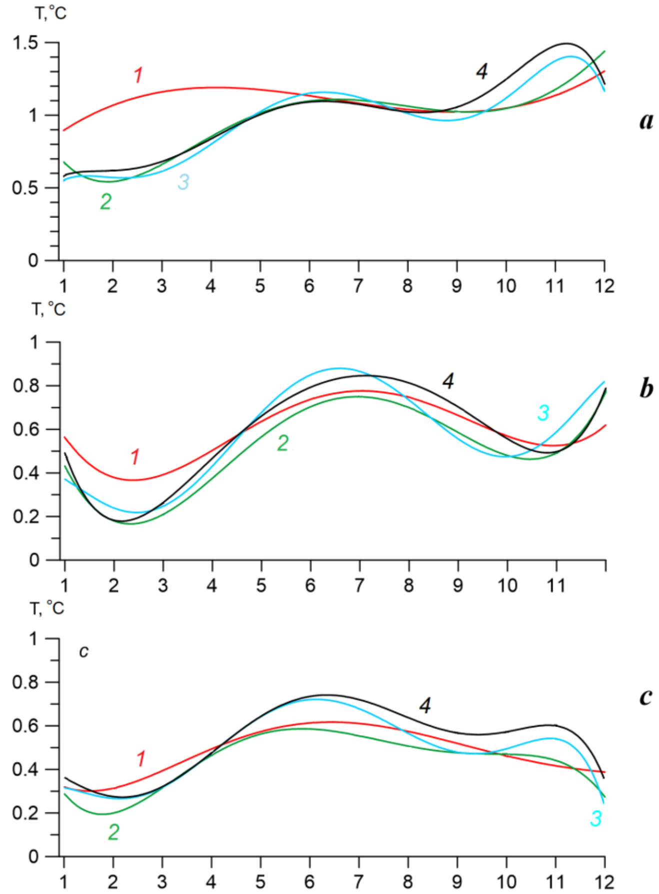


Fig. 6. Seasonal variability of mean standard deviations for sea surface temperature: interannual (*a*), 10-day (*b*) and daily (*c*) in 1991–2020. Digits stand for region numbers (see Fig. 1)

The spatial distribution of mean standard deviation of interannual SST variability is qualitatively consistent with the results of [11], but the quantitative estimates in this study are, on average, 10% lower. These differences are due not only to the use of different SST datasets, but also to discrepancies in the methods employed to evaluate variability across various time periods. Direct quantitative comparison with data from [12], which is dedicated to synoptic SST variability, is not feasible. In that study, variability was estimated over intramonthly intervals, thereby including fluctuation contribution from a broader frequency range. Consequently, the total variance for the 10-day and daily bands combined (Figs. 4 and 5) is 1.5–2 times lower than the values reported in [12]. However, the spatial patterns of 10-day variability remain qualitatively similar (Fig. 4).

Analysis of the seasonal variation in SST intensity revealed common patterns across all four regions (Fig. 6), as well as distinct regional features. All regions share a primary minimum in the intensity of fluctuations across all bands during winter and early spring, as well as a less pronounced local minimum in early autumn. The variability maximum occurs in summer and late autumn, with the autumn peak being more pronounced for interannual variability. Karkinit Bay is an exception, as it exhibits a relatively flat seasonal cycle of interannual fluctuations. Unlike the other areas, these fluctuations reach their maximum intensity in winter.

Temperature variations during the summer and autumn period are more intense in the Kerch–Feodosia region than in other areas, peaking in early summer along the SCC. The lowest values across all temporal variability bands are recorded in southwestern Crimea.

The seasonal pattern of interannual variability in the northeastern part of the sea, near the Kerch Strait, is in quantitative and qualitative agreement with the data from [11]. However, noticeable differences were found on the SCC: the present study recorded the maximum in autumn, whereas it was recorded in summer in [11]. Significant differences were also revealed in terms of synoptic variability. In [12], two distinct maxima were noted, in May and October. However, according to our data, the main maximum shifts to June, with October characterised as a local minimum.

Conclusion

The temporal variability characteristics of SST in the shelf areas along the Black Sea coast of Crimea were calculated using daily averages from the Black Sea High Resolution L4 Sea Surface Temperature Reprocessed dataset, with a spatial resolution of 0.05° × 0.05°, over the WMO 1991–2020 climate period.

Of four investigated regions, which are distinguished by their oceanographic characteristics, Karkinit Bay exhibits the most pronounced variability. This region is characterised by the largest seasonal range of SST and the highest intensity of variability (especially interannual) across all temporal bands during the winter period, which is particularly evident at the interannual scale. This type of interannual fluctuation regime is typical of shallow, ice-prone areas of the northwestern shelf, and is driven by sharp alternations between unusually warm and cold winters.

Conversely, the western region, which is adjacent to Karkinit Bay, exhibits the lowest level of temporal SST variability of all the areas of the Crimean shelf that were studied. In winter, the Rim Current warming influence reduces the seasonal temperature range significantly, while the Sevastopol anticyclone favours the accumulation and spread of warmer waters over the shelf. The low intensity of higher-frequency SST fluctuations is generally caused by weak water circulation in this area.

The Kerch–Feodosia region experiences the greatest SST variability across all bands in autumn, due to increased atmospheric synoptic activity in the northeastern part of the Black Sea and the exchange of water with the rapidly cooling Sea of Azov.

Conversely, this region exhibits the lowest seasonal range of SST due to the Rim Current warming effect in winter.

The characteristics of temporal SST variability along the SCC occupy an intermediate position between those of the Western region and the Kerch–Feodosia region. However, the seasonal range is larger here due to the absence of quasi-stationary anticyclonic eddies such as the Kerch and Sevastopol ones. These eddies promote the spread of Rim Current waters across the shelf area. Consequently, the Rim Current warming effect is largely confined to its core jet, rather than extending over the shelf. The summer peak in daily and 10-day variability is associated with frequent upwelling and downwelling events driven by variability in the wind field.

Overall, the Crimean shelf zone is characterised by increased spatial contrast in both overall intensity and seasonal variations of SST across different temporal scales. These parameters are therefore highly effective for categorising the region waters.

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Oksana A. Lukashova – literature review, calculations, preparation of graphical materials, analysis and interpretation of the results

Vladimir N. Belokopytov – study tasks statement, formation of the article structure, analysis and interpretation of the results

All the authors have read and approved the final manuscript.