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Impact of climate change on the assessment of the content of the indicator organic suspended matter and sea surface temperature of the Caspian Sea

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Keywords
Climate change
Sea surface temperature
Radiation balance
Temperature regime
Oil

Abstract

The location of Azerbaijan in relatively low latitudes determines an intense influx of solar radiation and an increased value of the radiation balance (RB) of the underlying surface. The surface of the Caspian Sea causes significant changes in the temperature of the lower atmosphere, thereby affecting the climate of the surrounding areas. Oil pollution of coastal waters and the spread of oil films over large areas have a significant impact on the temperature of the surface layer of air. Consequently, the human factor can influence climate formation and lead to further deterioration of the condition of coastal ecosystems. Limited ground-based observation networks and unreliable calculation methods prevent us from correctly identifying these changes. The application of statistical methods of analysis to study climate on a global scale is unrepresentative due to the limited capabilities of the ground-based observation network. The advantage of space means in studying the climatic characteristics of the territory of Azerbaijan allows, based on the transformation of satellite observation data and interpretation of the resulting time series, to solve these problems, with further presentation of the final information at the nodes of a one-degree regular grid. This allows you to observe changes not at one point in space, as was done, in the traditional vertical column of the atmosphere, but in the zonal profile (horizontal aspect).

1. Introduction

Water is the main essential resource of humanity, which is necessary for its survival. Today the relevance of problems related to water resources has been recognized throughout the world and is intensively studied. Water resources problems are highly interconnected with global climate change, as its influence on the distribution and circulation of water in the environment is observed (Amirgaliev et al. 2022).

A significant portion of the input radiation energy to the ocean is absorbed within a few meters of the surface, increasing the temperature of this ocean layer based on the daily cycle of the solar system. Lack of wind prevents water column mixing and causes the formation of a thermal layer at the ocean surface. Finding climatological variability of sea surface temperatures (SSTs) has been of interest to many researchers. This variability has showed a significant relationship with many factors, including wind, teleconnection indicators, and precipitation. Studies of the critical role of climate change on SST have been conducted in locations around the world (Ghasemifar et al. 2019).

Global warming and climate change are considered as important environmental problems. Environmental security is more pronounced with regard to the Caspian Sea. Due to the geopolitical and geo-economic dimensions on the one hand, and its unique characteristics on the other, this large lake is considerably fragile against environmental challenges. In fact, the innate isolation of the Caspian Sea makes its conditions with regard to global warming unique (Dero et al. 2020).

In the Caspian Sea, increases in the water temperature and air temperature over the water are of great importance. Any increase in water temperature is especially significant, as it decreases the area of winter ice cover in the Northern Caspian, weakens vertical water circulation in the deep sea, increases evaporation and activates chemical and biological processes (2nd State of Environment Report). In the last quarter of the twentieth century, the Caspian Sea has been impacted by global warming, with the air temperature over the water increasing by 0.7–0.8°C and the surface water layer by 0.4 -0.5°C (RPP, 2021).

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The sea surface temperature is the subsurface bulk temperature in the top few meters of the ocean, measured by ships, buoys and drifters. From ships, measurements of water samples in buckets were mostly switched in the 1940s to samples from engine intake water. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimeter thick) in the infrared or the top centimeter or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature (Bates et al. 2008).

In the Caspian Sea, long-term changes in water temperature are associated with long-term fluctuations in level. The analysis shows that in 1930...1940 the intense decrease in level had very little effect on the average annual water temperature. Therefore, the long-term norm changed only within 0.1...0.3 °C, but in some months, the change in water temperature was significant (Allahverdiev, 2016).

2. Method

Based on observational data from the NOAA series satellites, below is the accepted algorithm for estimating the albedo of organic suspended matter in water,

The albedo of the ocean-atmosphere system was presented in linearized form (Zeynalov, and Makhmudova, 2021)

$$A_{0.6} = A_{permanent\ 0.6} + A_{atm\ 0.6} + A_{glare\ of\ waves\ 0.6} + A_{org\ 0.6}, \quad (1)$$
$$A_{0.8} = A_{permanent\ 0.8} + A_{atm,\ 0.8} + A_{glare\ of\ waves\ 0.8} + A_{org\ 0.8}, \quad (2)$$

where $A_{permanent\ 0.6}$, $A_{permanent\ 0.8}$, – albedo of pure water in a transparent atmosphere (horizontal visibility range over 100 km), $A_{atm\ 0.6}$ and $A_{atm\ 0.8}$ – atmospheric dust albedo, $A_{glare\ of\ waves\ 0.6}$ and $A_{glare\ of\ waves\ 0.8}$ – albedo of the water surface due to solar glare and waves, $A_{org\ 0.6}$ and $A_{org\ 0.8}$ and organic suspended matter at wavelengths 0.6 and 0.8 mkm.

Based on the identity of the spectral behavior of the quantities A_{atm} and A_{glare} of waves for both wavelengths, that is, from the fact that:

1. the average ratio of changes in the albedo of the cloudless atmosphere at wavelengths of 0.8 and 0.6 μm is 0.92±0.08;
2. the average ratio of changes in albedo of the water surface due to solar glare and waves at wavelengths of 0.8 and 0.6 μm is 0.85 ± 0.15 (authors' estimate based on satellite observations for 5 years);
3. the average ratio of changes in albedo of the water surface due to organic suspensions at wavelengths 0.8 and 0.6 is 0.1±0.02,

the quantities A_{atm} and $A_{glare\ of\ waves}$ can be combined into A_{noise}. After this, the system of equations (1) – (2) is presented in the form (3)-(4):

$$A_{0.6} = A_{permanent0.6} + A_{noise0.6} + A_{org0.6}, \quad (3)$$
$$A_{0.8} = A_{permanent0.8} + A_{noise0.8} + A_{org0.8}, \quad (4)$$

Next, taking into account the above spectral contrasts of the albedo of organic suspensions, the albedo of atmospheric aerosol and the albedo due to solar flare and waves, we present expressions (3) and (4) in the form (5) and (6):

$$A_{0.6} = A_{permanent\ 0.6} + A_{noise\ 0.6} + A_{org\ 0.6}, \quad (5)$$
$$A_{0.8} = A_{permanent0.8} + 0.85 * A_{noise\ 0.6} + 0.1 * A_{org}, \quad (6)$$

Solving this system of equations, we obtain the following expressions for the albedo of organic suspensions and the total albedo due to the atmosphere and waves:

$$A_{org\ 0.6} = (0.85 *(A_{0.6} - A_{permanent\ 0.6}) - (A_{0.8} - A_{permanent\ 0.8}) / (0.85 - 0.1), \quad (7)$$
$$A_{noise\ 0.6} = A_{0.6} - A_{permanent\ 0.6} - A_{noice\ 0.6} \quad (8)$$

The water albedo values for a transparent atmosphere, $A_{permanent}$ 0.6 and $A_{permanent}$ 0.6, were calculated using the LOUTRAN–5 procedure.

The main role is played by the radiation temperature of the underlying surface, estimated from measurement data at wavelengths of 11 and 12 μm.

NOAA offers coefficients for radiation temperatures at 11 and 12 μm, as well as satellite angle considerations, as follows:

$$SST = k_1 * T_{11} - k_2 * T_{12} + k_3 * (T_{11} - T_{12}) * (sec(\tau) - 1) \quad (9)$$

where SST is the radiation temperature of the water surface; T_{11} and T_{12} are radiation temperatures at wavelengths of *11* and *12 μm*, respectively; k_1,k_2 *and* k_3 - weighting coefficients; the values of k1 and k2 are taken equal from 1 to 4, and the value of the coefficient k1 is taken to be approximately one greater than the values of *k2; k3* - 0.7; τ– satellite sensing angle.

3. Results

Surface water temperatures in the Caspian Sea, as in other oceanic waters, are generally determined by air temperature, heat storage, wind properties (mixing) and advection. In different regions of this continental sea area, in addition to the temperature factors common to all regions, various factors dominate.

In the northern part of the Caspian Sea, firstly, the influence of river flow is felt - warmer continental runoff in spring and colder continental runoff in autumn. In the Central Caspian Sea, there is a rise in deep waters off the eastern and western coasts and temperature changes of up to 15°C off the eastern coast. In the southern part of the Caspian Sea, there is a mixing of winter winds and advection of water from the center of the Caspian Sea. During the daytime in spring and summer, sea water temperatures are universally characterized by the presence of areas of warm water exceeding 3°C. Heating and cooling zones are clearly visible in shallow water in spring and autumn, respectively, and the ratio of heating and cooling is higher as the depth of the water area decreases, i.e. less heat is accumulated 8. (Lyushvin P.V. 1996).

Below are maps of the average monthly fields of organic suspended matter albedo (ASSA) and surface water temperature (SST) for 12 months from November 2001 to October 2002, as well as graphs of the course of these variables in individual areas of the sea.

The maps are based on survey data with a spatial resolution of about 1.5 km. In total, the original image has 430 by 700 pixels. In each, the value of the measured quantity is specified: albedo with an accuracy of 0.1%, temperature with an accuracy of 0.2°C. The initial information, which may not be complete everywhere due to cloudiness, ice or non-compliance with information control criteria, is recalculated to a 43 by 35 node grid with a step of 1.4 geographic degrees. Optimal interpolation was used under the assumption that the fields are isotropic. Based on the data received, maps were drawn. The A_{org} and SST maps are equipped with corresponding color scales, the same for all months.

In all figures, on the left are the fields, A_{org}, %, and on the right are the fields, SST, °C. Ice boundaries are shown at the end of the month.

In the graphs presented below, the data was obtained by averaging within ten numbered sections into which the sea is divided. A diagram of sections indicating the number of nodes falling into each of them is shown in the following fig. 1 on the left; a diagram of the numbers of sections and the position of their geographical centers, to which the average values are assigned, is on the right. Initial data are given in tables. All drawings are made in vector graphics formats.

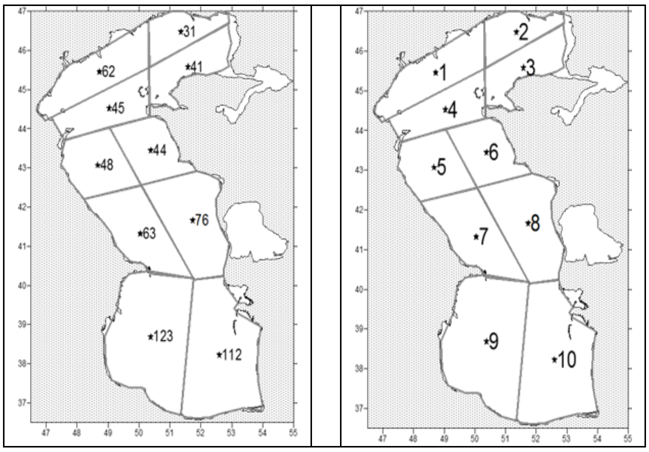

Figure 1. Diagram of sections indicating the number of nodes falling into each of them (on the left) and the numbers of sections with the position of their geographic centers, to which the average values are assigned (on the right).

Table 1. Average monthly values of A_{org} for sections of the Caspian Sea

No	X	Y	111	112	201	202	203	204	205	206	207	208	209	210
1	48,7	45,5	2,3	0,0	0,0	5,1	4,1	4,2	3,4	3,6	3,4	3,4	4,2	4,5
2	51,3	46,4	2,8	0,0	0,0	0,0	6,9	8,3	6,1	6,4	4,2	4,5	5,8	7,5
3	51,6	45,7	2,0	0,0	0,0	7,9	7,3	9,9	7,5	7,5	5,5	5,1	5,6	7,5
4	49,1	44,5	1,9	4,2	3,5	3,2	2,8	2,7	1,9	2,0	1,8	2,0	2,3	2,6
5	48,6	43,0	1,5	2,3	2,5	2,3	2,2	1,6	1,3	1,5	1,5	1,6	1,9	1,9
6	50,4	43,4	1,5	2,6	2,2	1,1	2,2	1,4	1,3	1,5	1,4	1,5	1,7	1,6
7	50,0	41,3	1,3	2,6	2,6	2,0	2,4	1,3	1,5	1,5	1,5	1,4	1,8	1,9
8	51,8	41,6	1,3	2,5	2,4	1,3	2,3	1,5	1,4	1,5	1,5	1,4	1,8	1,7
9	50,4	38,7	1,5	3,2	2,7	1,9	2,4	1,5	1,6	1,6	1,6	1,6	1,9	2,2
10	52,6	38,2	1,3	3,4	2,8	2,2	2,4	2,2	1,9	2,1	2,0	2,1	2,3	2,5

Note to the table. Column No contains the numbers of the sections, columns X and Y contain the longitudes and latitudes of the centers of the sections, the remaining columns are marked with month numbers so that November 2001 is designated as 111, October 2002 as 210, etc.

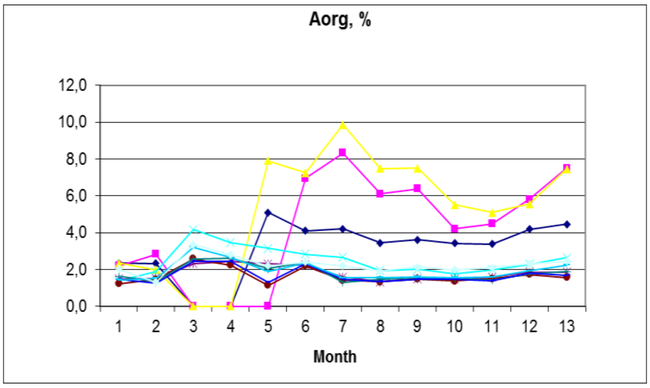

Figure 2. Graphs of the course of average monthly Aorg values for ten sections of the Caspian Sea.

Table 2. Average monthly values of SST by area Caspian Sea

No	x	Y	111	112	201	202	203	204	205	206	207	208	209	210
1	48,7	45,5	9,2	-0,5	-0,5	3,2	7,8	12,8	17,9	23,4	29,0	27,7	22,5	16,9
2	51,3	46,4	9,0	-0,5	-0,5	-0,5	4,5	10,6	16,9	23,2	28,7	27,5	21,6	15,5
3	51,6	45,7	9,4	-0,5	-0,5	1,0	5,9	11,0	17,4	23,5	28,2	27,1	21,3	15,5
4	49,1	44,5	12,7	3,3	1,9	3,5	6,5	11,0	15,5	22,3	27,4	26,9	22,6	19,7
5	48,6	43,0	14,9		7,0	7,1	7,6	10,3	13,9	20,0	26,0	27,1	23,6	21,2
6	50,4	43,4	14,6	7,1	7,9	7,3	8,5	10,2	13,5	19,2	25,5	26,3	22,7	20,1
7	50,0	41,3	15,6	8,9	8,2	8,5	9,0	10,6	14,1	19,7	25,4	26,6	24,1	21,6
8	51,8	41,6	15,5	9,1	9,2	9,0	9,5	11,0	14,4	19,6	25,4	26,1	23,2	20,8
9	50,4	38,7	18,2	12,0	10,8	10,6	11,8	13,4	16,9	22,4	26,9	27,8	25,7	23,9
10	52,6	38,2	18,0	11,3	11,6	11,1	12,5	14,0	17,2	22,9	27,6	28,4	26,6	24,8

Note to the table. Column No contains the numbers of the sections, columns X and Y contain the longitudes and latitudes of the centers of the sections, the remaining columns are marked with month numbers so that November 2001 is designated as 111, October 2002 as 210, etc.

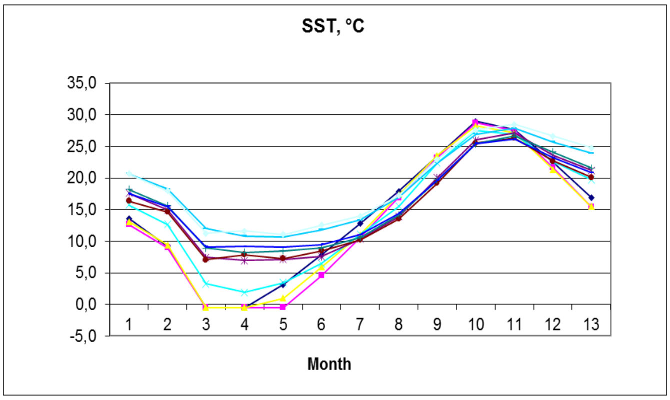

Figure 3. Graphs of the course of average monthly SST values for ten sections of the Caspian Sea.

The resulting graphs show the course of changes in the values of A_{org} and SST according to the retrospective analysis of the Caspian Sea, divided as shown in Fig. 1 for ten test areas, determination of the content of organic suspended matter in the surface waters of the Caspian Sea can give fundamental conclusions on the course of the impact of anthropogenic factors of changes in metrological conditions on the natural factors of the territory of Azerbaijan.

The main systematic data from the Global Hydro meteorological Network's ground stations and satellite monitoring can be received through the National Oceanic and Atmospheric Administration's (NOAA) server network. The National Environmental Satellite, Data, and Information Services (NESDIS) Directorate has a separate division responsible for NOAA satellites and information. As part of NESDIS, the Office of Satellite Data Processing and Distribution (OSDPD) processes and distributes satellite data, enabling data and information from environmental satellites to be processed, systematized, and made available to users in the United States and other countries. The ultimate goal of user maintenance is achieved through appropriate information production through the following three agencies: Satellite Services Department (SSD); Information Processing Department (IPD): Direct Services Department (DSD) (Zeynalov, I., Akhmedova, R., Akhmedova, A., Rustamova, A. 2023).

4. Conclusion

As a result of the studies performed, the possibility of operational monitoring of the state of the studied values of SST and Aorg throughout the entire Caspian Sea was shown. In specially selected areas, a retrospective review of conditions that developed over a certain period of time. The resolution of satellite information and the adopted processing techniques make it possible to recreate the picture of the spatiotemporal variability of these quantities with the degree of detail that cloud conditions only allow.

It is obvious that other means of observation, except artificial earth satellites, are not capable of even approaching the achieved indicators. At the same time, data prepared by specialists in the USA and Europe and published on the Internet are characterized by insufficient detail and methodological shortcomings due to the global nature of the information presented. The method proposed by the authors for monitoring the sea area can be actually tested and reasonably used only after carrying out control sub-satellite observations.

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