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Analysis of the sea surface temperature (SST) of the Caspian Sea from NOAA satellites

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Abstract

The sea surface temperature (SST) of the Caspian Sea as a whole is determined by air temperature, depth, that is, heat reserve, wind characteristics (mixing) and advection. In different regions of this continental sea, in addition to the connection with air temperature common to all regions, their own factors dominate. For the Northern Caspian, this is primarily the influence of river runoff - warm continental runoff in spring and cool in autumn. In the Middle Caspian, deep water rises near the eastern and western shores, reaching a temperature contrast near the eastern shore. In the Southern Caspian, this is winter wind mixing and advection of waters from the Middle Caspian. During the daytime, during the spring and summer months, the warming of the sea manifests itself everywhere in the form of areas of warm water with temperature contrasts in calm zones. In shallow water in the spring and autumn months, zones of heating and cooling are clearly visible, respectively, and the rate of heating and cooling is the higher, the shallower the depth of the sea, that is, the lower its heat reserve. The paper analyzes the available modern methods and means for determining the surface water temperature of the Caspian Sea. For their detection, data obtained by NOAA satellites and the AVHRR Pathfinder instrument (high-resolution radiometer) installed on them are used. In addition, the main regularities in the atmosphere-sea system are revealed according to the average annual values of their changes over a long period.

1. Introduction

Technogenic pollution of the Caspian Sea is one of the most important modern problems of our republic. Its negative consequences affect both the state of the ecosystem and the successful development of the entire region for the purpose of recreation. Therefore, an urgent need arose for measures to protect the purity of the aquatic environment and organize special studies of the northern part of the Azerbaijan coast of the Caspian Sea using remote sensing methods.

Once in the water, techno genic impurities are subject to natural, hydro meteorological processes occurring in the sea. Under the influence of temperature, mechanical mixing, physical and chemical decomposition, they dissolve or precipitate. Their active decomposition is facilitated by the activity of microorganisms, in particular oil-oxidizing bacteria, animal filtrates. A special place in this regard is occupied by petroleum hydrocarbons, the most characteristic pollutant of the region, as well as their accompanying phenols and synthetic surfactants [1].

The Caspian Sea is characterized by considerable variability of its hydrometeorological and hydrodynamic regimes which are influenced by both climate (global warming) and anthropogenous (e.g., variations of the Volga River discharge) factors. This long-term variability of Caspian Sea regimes, as well as need of control of ecological state of the sea, necessitates comprehensive monitoring of changes in its main parameters [sea level and sea surface temperature (SST)]. In the condition of rare in situ measurements, appropriate satellite information with good spatial-temporal resolution becomes the base of reliable and regular information on various parameters of the Caspian Sea [2].

Characterizing temporal and spatial patterning of SST (at a fine-scale) and evaluating the impacts and consequences of global warming in the Caspian Sea is critical to implement any conservational plans in this unique aquatic ecosystem as the Earth's largest inland waterbody which hosts unique and vulnerable living resources. Previous studies, mainly focused on inter-annual warming and seasonal variation of SST in the Caspian Sea. For instance, Kostianoy et al. [3] reported that mean annual SST in the southern Caspian Sea increased about 0.8 °C during the period 1982–2015 (comparing to the preceding period) which is resulted from the global warming. However, a comprehensive perspective and detailed characterization of the temporal and spatial variability of SST (timing, seasonality, frequency and intensity of warming periods and extreme events, etc.) is still lacking in the Caspian Sea. This study mainly focuses on the long-term SST to investigate the dominant features of spatiotemporal variability patterns of SST in the Caspian Sea based on an analysis of 35 years (1982–2016) of satellite-based fine-scale data.

The work will analyze changes in water surface temperature (SST) values in individual areas of the Caspian Sea, taking into account various anthropogenic manifestations.

2. Material and Method

Under the conditions of temporal and spatial heterogeneity of hydrodynamic processes, calculations of the distribution of pollutants (PS) in the water column are usually carried out by numerical integration methods, taking into account the main characteristics of pollution sources, their power, discharge frequency, etc.

The proportion of impurity (mathematical expectation) is of considerable interest from the point of view of studying the "instantaneous distribution" of pollutants. Using other approaches to solve these problems, which are based on traditional models of fluid motion, suspended particles and the transfer of matter in a turbulent medium. For example, according to the dimensional method, when analyzing the balance equation of migration flows of pollutants, taking into account their spatial heterogeneity, as well as their total removal from the marine ecosystem, AC (assimilation capacity) is written in a general form (Equation 1):

$$A_i = k_i \frac{V}{\tau_i} C_i, \quad (1)$$

Where k_i - is the safety factor that determines the environmental conditions of the pollution processes selected in our calculations, and their spatial and temporal distribution.

When assessing the AC of the marine ecosystem, the concept of the $k_i$coefficient was expanded due to the information on the space-time heterogeneity (k_{i2}) in the distribution of pollutants included in the k_i calculation scheme, thus (Equation 2):

$$k_i = k_{i1} \cdot k_{i2} \quad (2)$$

Where - the safety factor (k_i) determines the environmental conditions for the flow of pollution processes selected in our calculations, and -(k_{i2}), - spatial distribution for τ - or rather $^1/_\tau$- lifetime in the ecosystem of one or another (i) - contaminant.

At the same time, one should take into account the fact that the concentration (i) in sea water (averaged by volume) was chosen in such a way that at no point in the studied zone the content of pollutants exceeded possible "critical values".

At the same time, the value of k_i, as the ratio of the allowable concentration to the critical one, is preserved. The difference is that, in addition to the ecological one, the effect associated with the spatial and temporal heterogeneity of pollution fields (k_{i2}) is taken into account. In addition, in accordance with the above, it is possible to determine the ratio of the threshold concentration to semi-lethal (k_{i1}) and the overall safety factor (AC), expressed by the product of Equation (2). Since the task of the authors was to study the spatial and temporal heterogeneity of the concentration of pollutants, the safety factors were calculated to assess the AC of the ecosystem in relation to hydrocarbons, phenols and surfactants [4].

When calculating AC for petroleum hydrocarbons related to the part of the water area up to 10 - 15 m isobaths, taking into account river runoff, the volume of water for the I band was $V_A = 2{,}73$ км^3, $V_B = 4{,}55$ км^3, $V_C = 3{,}9$ км^3 (Table 1).

$1/\tau$ is the residence time.

The basis of the AE concept are the results of diverse oenological studies showing that an integral feature of the functioning of the marine ecosystem is the predominance of the biotic component in the formation of migration flows and the removal of chemicals [5].

The value of AC depends on many natural and anthropogenic factors, such as the speed of currents, turbulence, water exchange, water temperature, the functioning of biotic components, as well as on the chemical and physical properties of the pollutant (PS) entering the marine ecosystem [1].

Information about the temporal variability of surface temperature is necessary to determine biological life, ice regime, evaporation amount, heat balance, climate of the adjacent sea area, etc. For example, the expenditure part of the heat balance of the Caspian Sea is mainly determined by the amount of water evaporated from the sea surface, which in turn is calculated from the difference between the temperature of the air and the surface layer of the sea. Under the temperature of the water surface of the sea, we mean the thermodynamic temperature of the upper layer with a thickness of about 0.5 m.

The change in temperature during the month, depending on the time of year and meteorological conditions, in different areas of the sea occurs in different ways. In this paper, the authors consider the time structures of the surface temperature. Knowledge of such a structure makes it possible to construct maps of the temperature field both on the basis of individual contact and remote sensing measurements [6].

Information about the temporal variability of the surface temperature is required to study biological communities, ice regime, evaporation amount, heat balance, climate conditions of the adjacent sea area etc. The temperature change during the month, depending on season and meteorological conditions, in different areas of the sea goes in different ways. This work considers the temporal structures of the surface temperature. This makes it possible to compile maps of temperature fields both on the basis of individual contact measurements, and from satellite remote sensing data.

Table 1. Assimilation capacity for oil hydrocarbons of the Northwestern part of the Azerbaijan coast of the Caspian Sea.

Season	C_{cp} (mg/l)	C_{max} (mg/l)	Zone A Amount of pollutant	$1/\tau$	AC (τ)	
					I band	II band
			Zone A			
Winter	0,09	0,163	0,552	0,0762	1,763	8,525
Spring	0,10	0,248	0,403	0,09960	1,096	5,341
Summer	0,10	0,170	0,588	0,10677	1,400	6,771
Autumn	0,09	0,200	0,450	0,09718	1,137	5,501
			Zone B			
Winter	0,09	0,175	0,544	0,0762	2,9235	15,03
Spring	0,11	0,269	0,409	0,09960	2,0552	11,29
Summer	0,08	0,204	0,392	0,10677	1,3118	7,21
Autumn	0,09	0,25	0,360	0,09718	1,5169	8,33
			Zone C			
Winter	0,07	0,125	0,500	0,0762	1,9875	8,82
Spring	0,14	0,349	0,401	0,09960	2,198	9,75
Simmer	0,10	0,182	0,549	0,10677	1,968	5,55
Autumn	0,07	0,256	0,273	0,09718	0,7669	3,48

3. Study Area

Author the distribution of the studied values of sea surface temperature (SST) and organic albedo (Aorg) over the entire water area of the Caspian Sea was analyzed (Figure 1).

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. (Table 2).

Table 2. 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

The albedo of the Atmosphere-Ocean System was presented in a linearized form (Equation 3-4):

$$A_{0.6} = Apost_{0.6} + Aatm_{0.6} + Aglint\ wav_{0.6} + Aorg_{0.6} \quad (3)$$

$$A_{0.8} = Apost_{0.8} + Aatm_{0.8} + Aglint\ wav_{0.8} + Aorg_{0.8} \quad (4)$$

where Apost 0.6, Apost 0.8, is albedo of pure water in a transparent atmosphere (horizontal visibility range over 100 km), Aatm 0.6 and Aatm 0.8 – albedo of atmospheric dust, Aglint wav 0.6 and Aglint wav 0.8 – the albedo of the water surface due to solar glint and waves, Aorg 0.6 and Aorg 0.8 – the albedo of the organic suspension at the wavelengths of 0.8 and 0.6 microns.

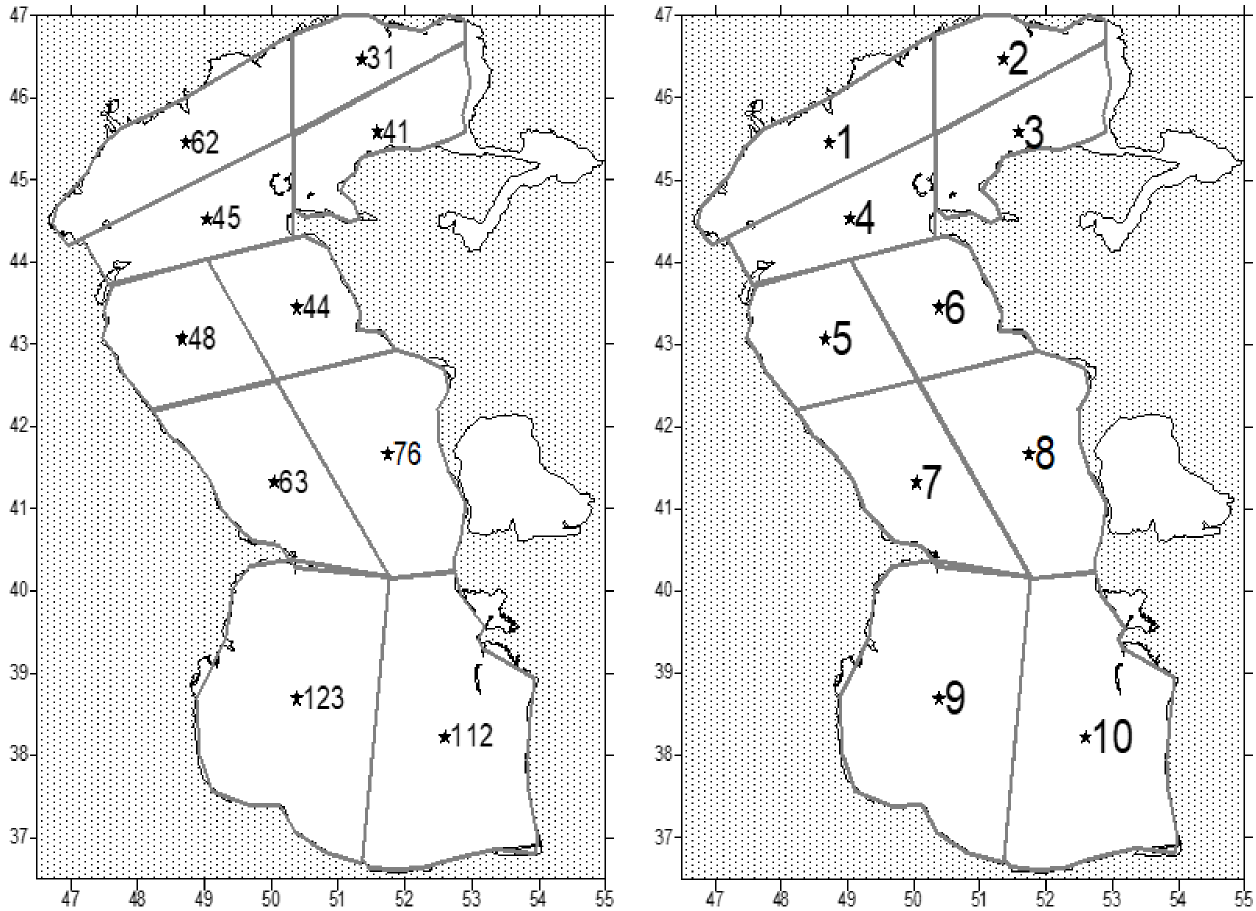

Figure 1. A diagram of the sections indicating the numbers of nodes that fall into each of them (on the left) and the numbers of the sections with the position of their geographical centers, where the average values are assigned (on the right).

Based on the identity of the spectral path of the Aatm and Aglint wav values for both wavelengths, that follows from: the average ratio of changes in the albedo in clear air at wavelengths of 0.8 and 0.6 microns is 0.92±0.08; the average ratio of changes in the albedo of the water surface due to the waves and solar glint at wavelengths of 0.8 and 0.6 microns is 0.85± 0.15 (the authors assessment from satellite observations in 5 years); the average ratio of changes in the albedo of the water surface due to organic suspensions at wavelengths of 0.8 and 0.6 microns is 0.1±0.02. The values of Aatm and Aglint wav could be combined into A_{noise}. After that, the system of Equations (1) – (2) is represented as Equation (5)-(6):

$$A_{0.6} = Apost_{0.6} + Anoise_{0.6} + Aorg_{0.6} \tag{5}$$

$$A_{0.8} = Apost_{0.8} + Anoise_{0.8} + Aorg_{0.8} \tag{6}$$

Further, considering the above spectral contrasts of the albedo of organic suspensions, albedo of atmospheric aerosol and albedo due to solar glint and waves, we can represent expressions in Equation (3) and (4) in the form of Equation (7) and (8):

$$A_{0.6} = Apost_{0.6} + Anoise_{0.6} + Aorg_{0.6} \tag{7}$$

$$A_{0.8} = Apost_{0.8} + 0.85 * Anoise_{0.6} + 0.1 *Aorg_{0.6} \tag{8}$$

By solving this system of equations, we get the following representations for the albedo of organic suspensions and the total albedo due to the atmosphere and waves (Equation 9-10):

$$Aorg_{0.6} = (0.85 *(A_{0.6} – Apost_{0.6}) – (A_{0.8} – Apost_{0.8}) / (0.85 – 0.1) \tag{9}$$

$$Anoise_{0.6} = A_{0.6} – Apost_{0.6} – Anoise_{0.6} \tag{10}$$

Water albedo values for a transparent atmosphere Apost $_{0.6}$ and Apost $_{0.6}$ are calculated according to the LOUTRAN–5 procedure.

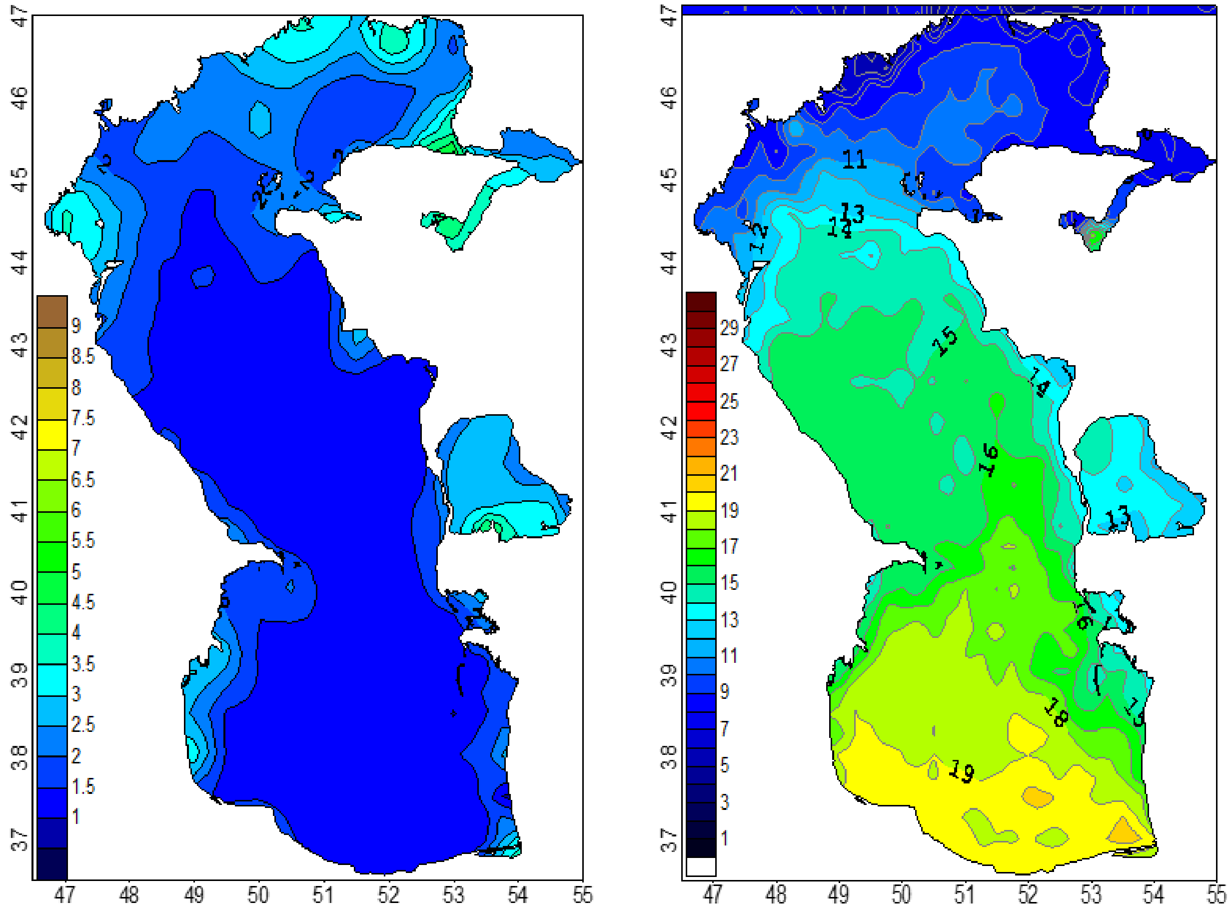

Figure 2. Average value of A_{org} (left) and SST (right) for November 2001.

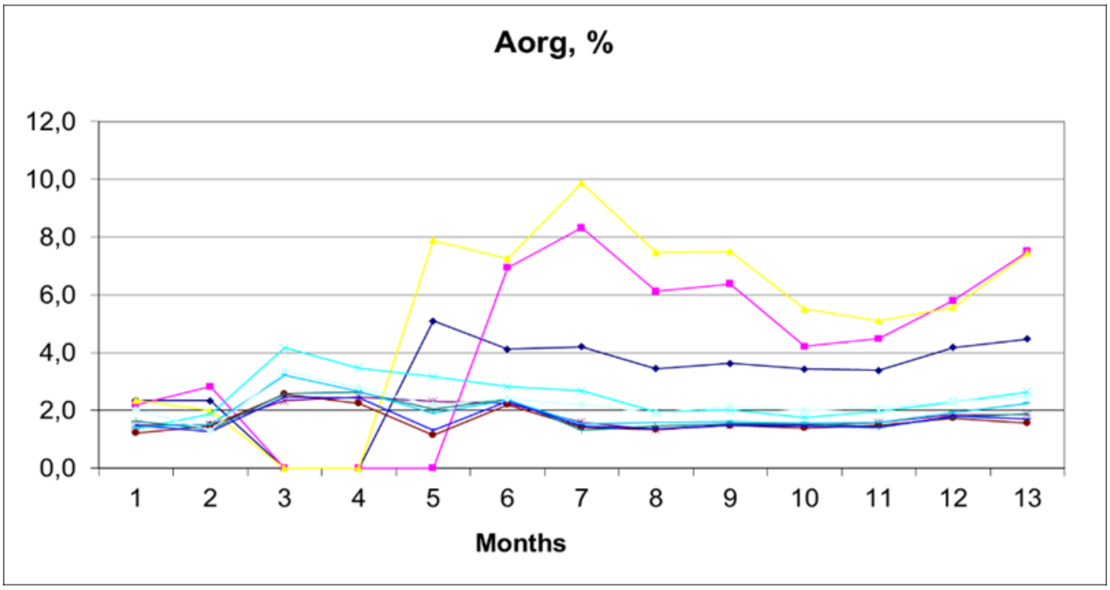

Figure 3. Graphs of the average monthly Aorg values for ten areas of the Caspian Sea.

The described approach to the albedo of organic suspensions assessment reduces by three times the errors in the estimation of the albedo of organic suspensions; however, it either does not separate the contributions to the total albedo of the ocean-atmosphere system due to the atmosphere and waves, and the errors of calculations in shallow water are not eliminated due to the reflected solar radiation from the bottom and turbid inorganic suspensions [7].

The location of Azerbaijan in relatively low latitudes causes an intense influx of solar radiation and an increased value of the radiation balance (RB). The water surface of the Caspian Sea makes significant changes in the temperature of the lower layers of the atmosphere, and thus affects 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 air layer. As a result, there is a significant change in albedo, which has a significant impact on the sea surface temperature (SST) and the meteorological conditions of Azerbaijan. Anthropogenic factors can influence climate formation and provoke further deterioration of coastal ecosystems. The limited network of ground-based observations and the insufficient reliability of the calculation methods do not allow one to correctly determine these changes. Based on this, it becomes relevant to solve problems and determine the WST of the underlying surface and its components according to satellite measurements on a regional scale. 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 the interpretation of the resulting time series, to solve these problems, with further presentation of the final information in the nodes of a one-degree regular grid. This makes it possible to observe changes not at one point in space, as was done, in the traditional vertical column of the atmosphere, but in a zonal profile (horizontal aspect). Further expansion of the obtained time series for the study of climate in the zonal profile and comparison of these data with the vertical column of the atmosphere will give solid forecasts for climate change in the territory of Azerbaijan.

The site numbers, columns X and Y are the longitudes and latitudes of the centers of the sites, the remaining columns are marked with the numbers of the months so that November 2001 is designated as 111, October 2002 as 210, etc. (Table 3).

Table 3. Average monthly values of SST in 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	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

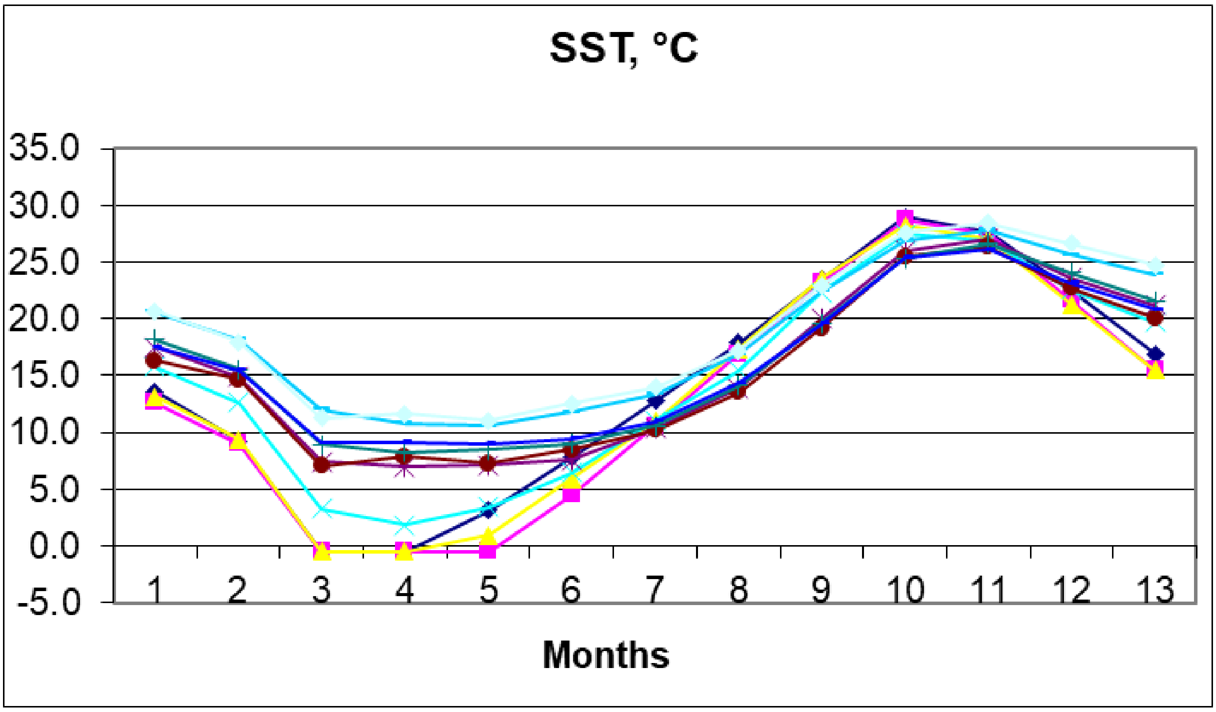

Figure 4. Graphs of the course of average monthly SST values for ten sections of the Caspian Sea.

The resulting graphs show the course of changes in the Aorg and SST values according to a retrospective analysis of the Caspian Sea, divided as shown in Figure 2-4, for ten test sites, the determination of the content of organic suspensions in the surface waters of the Caspian Sea can give solid conclusions in the course of the impact of anthropogenic factors of changes in metrological conditions on the natural factors of the territory of Azerbaijan [8].

3. Results

The main systematized data of the ground hydrometeorological network stations and satellite supervision for the whole of globe can be received by using the server network of the USA National Ocean and Atmosphere Administration (NOAA). There is a separate entity of NOAA Satellites and Information with the body of the National Environmental Satellite, Data and Information Service (NESDIS). Within the framework of the NESDIS is functioning the Office of Satellite Data Processing and Distribution (OSDPD) for processing and distribution of satellite data which provides processing, systematization and supply to users in the USA and other countries data and information from the environmental satellites. The final goal of user`s maintenance is reaching by appropriate information production over the following three institutions: Satellite Service Division (SSD); Information Processing Division (IPD): Direct Services Division (DSD).

There are number of other institutions for maintenance of the initial data for monitoring of the environment. For the considered purposes in the paper has been used the data from the IPD divisions of the Satellite Active Archive (SAA) through the Internet network. In the network is presented an opportunity of selection of such information which refers to Advanced Very High-Resolution Radiometer (AVHRR); Pathfinder – specialized software. Information production of the AVHRRPF (sometimes calls as PATMOS) with a free of access represents of the number of USA satellites NOAA- 7-9 – and 14.

Within the framework of the PATMOS- A1 statistical characteristics have been calculated using the indicated above satellites for intensive outgoing radiation in all five channels of visible area of the spectrum, two channels as called "atmosphere transparency windows" for 10-12 micrometers and near infrared area for elimination of impact of atmospheric cloudless and cloudy conditions. Cloudy cover statistical characteristics have been calculated where condition describes by a huge of parameters.

Based on the PATMOS – A2 version statistical characteristics of the atmospheric aerosol optical thickness above oceans as well as values of the absorbed solar (short wavelength) radiation and thermal (long wavelength) radiation have been calculated which define radiation balance on the top of an atmosphere. In the climate and climate change investigations usually use a monthly average value of appropriate characteristics.

Below presents some of data analysis results off the PATMOS- A2 information production for the term of 1982-2000 in two allocated areas of Near - Caspian region (from 38° up to 42° north longitude from 44° to 52° east latitude; and from 34° up to 50° north longitude, from 44° up to 56° east latitude) incorporation with data of a ground measuring network based on characteristics, as monthly average values of air temperature, atmospheric pressure and average speed of a wind at the surface level. The first of selected areas approximately covers the territory of Azerbaijan and second - wider area of territory of Russia, Azerbaijan, Georgia, Iran, Turkmenistan, and Kazakhstan. The specified data of a ground network are accessible through the Internet network and other information center of the USA national climate data center (NCDC).

It can be considered some of examples of interpretation to be received information production for the purposes of investigation of climate variability of selected two foregoing mentions Near Caspian region for the last 20 years [9].

The paper analyzes the changes in the values of sea surface temperature (SST) for individual sections of the Caspian Sea, taking into account various manifestations of an anthropogenic nature. The surface temperature of the waters of the Caspian Sea as a whole is determined by air temperature, heat storage, wind characteristics (mixing) and advection. In different regions of this continental sea, in addition to the connection with air temperature common to all regions, some of their own factors also dominate.

For the Northern Caspian, this is primarily the influence of river runoff - warm continental runoff in spring and cool in autumn. In the middle of the Caspian Sea, the rise of deep waters near the eastern and western shores reaches temperature contrasts of up to 15° C near the eastern shore. In the South Caspian, this is winter wind mixing and advection of waters from the Middle Caspian. In the daytime in the spring-summer months, the heating of the sea manifests itself everywhere in the form of patches of warm water with temperature contrasts of more than 3^0C - a calm zone. In shallow water in the spring and autumn months, zones of heating and cooling are clearly visible, respectively, and the rate of heating and cooling is the higher, the shallower the depth of the sea, that is, the lower its heat reserve. The work carried out by the author confirmed the correctness of the proposed methodological approach and the basic assumptions for organizing experimental satellite monitoring of sea surface temperature fields: - the use of an algorithm for taking into account the distorting influence of the atmosphere makes it possible to reduce both geographical due to shallow water and meteorological due to taking into account the distorting influence of aerosol formations, limitations in interpretation of satellite spectrum-zonal information; - the choice of satellite NOAA as a satellite platform for operational background monitoring of the sea surface and TERRA, ESA as platforms for episodic surveys under existing conditions is the only possible one in case of extreme situations. Both geographical due to shallow water, and meteorological due to taking into account the distorting influence of aerosol formations, limitations in deciphering satellite spectral-zonal information; - the choice of satellite NOAA as a satellite platform for operational background monitoring of the sea surface and TERRA, ESA as platforms for episodic surveys under existing conditions is the only possible one in case of extreme situations. Both geographical due to shallow water, and meteorological due to taking into account the distorting influence of aerosol formations, limitations in deciphering satellite spectral-zonal information; - the choice of satellite NOAA as a satellite platform for operational background monitoring of the sea surface and TERRA, ESA as platforms for episodic surveys under existing conditions is the only possible one in case of extreme situations.

The change in temperature during the month, depending on the time of year and meteorological conditions, occurs differently in different areas of the sea. In this paper, the time structures of the surface temperature are considered. Knowledge of such a structure makes it possible to construct maps of the temperature field both on the basis of individual contact and satellite remote measurements [10].

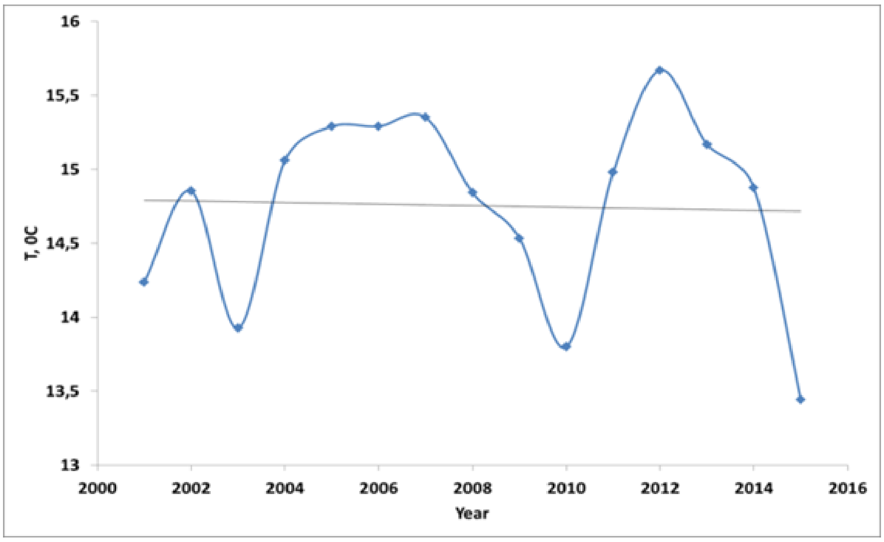

Figure 5. Data of water surface temperatures in the Caspian Sea from satellites of the NOAA series with a resolution of 50 km.

Table 4. Average monthly values of SST for the Caspian Sea.

Year	January	February	March	April	May	June	July	August	September	October	November	December
2001	7,87	4,03	6,99	9,47	16,17	18,20	24,91	24,91	21,15	15,55	12,71	8,90
2002	7,52	6,28	7,91	10,22	15,55	15,55	25,82	26,38	22,69	18,37	13,21	8,73
2003	6,86	5,58	5,11	7,11	14,80	16,70	24,24	26,30	21,64	17,50	12,40	8,87
2004	7,90	7,59	8,62	10,13	15,59	19,43	25,36	26,35	22,14	15,73	13,52	8,38
2005	7,43	5,30	6,09	10,21	16,91	20,08	26,03	26,01	24,13	17,44	13,45	10,41
2006	6,97	5,74	7,03	10,39	15,54	23,94	25,79	26,49	23,22	17,74	12,57	8,08
2007	7,36	6,33	6,99	8,96	16,12	22,62	26,17	26,74	23,93	17,34	12,82	8,82
2008	5,38	5,87	6,28	10,85	15,95	19,65	25,25	26,24	21,93	17,40	13,60	9,71
2009	6,06	5,41	6,89	8,89	15,33	20,16	25,55	24,54	22,08	17,84	12,48	9,17
2010	8,02	4,96	5,89	9,72	15,76	7,26	26,74	23,00	22,42	16,89	13,19	11,75
2011	8,22	6,54	5,66	9,26	16,43	23,56	26,04	26,27	22,12	16,39	11,37	7,90
2012	6,31	5,71	5,66	10,96	17,68	24,14	26,45	24,61	22,76	19,21	14,30	10,24
2013	7,00	5,95	7,15	10,85	16,33	22,55	26,26	25,85	21,75	16,28	13,35	8,69
2014	7,45	5,32	6,38	9,98	16,91	22,03	25,94	26,29	22,13	16,31	11,28	8,48
2015	6,96	5,46	6,65	9,67	16,09	22,28	7,71	24,95	24,41	16,49	12,12	8,51
Total	7,15	5,74	6,62	9,78	16,08	19,88	24,55	25,66	22,57	17,10	12,82	9,11

For the selected research region, Figure 5 shows the values of the water surface temperature for the selected 14 years of continuous observations (from January 2001 to December 2015). The left side of Figure 5 shows the corresponding average annual values (averaged over 12 months) for each year of the observations under consideration. One can see a fairly smooth course of monthly averages for the selected region with maxima in 2002, 2005, 2013. The average annual values of the corresponding values vary approximately from 14.2^{0}C to 15.8^{0}C. The presence of such smooth curves for monthly averages reflects the time course of the temperature of the "earth's surface-atmosphere" system over a given region. Much more complex is the behavior of the average annual values of the studied quantities for each year out of the selected 14 years of observations. One can note an almost systematic deviation in the average annual values of the water surface temperature for the selected region. For example, according to the curve in Figure 5 in 2002, these values were 15^{0}C and 15.06^{0}C for the selected "square" of the territory of Azerbaijan and the entire Caspian region, respectively; in 2001 - 14.5^{0}C and 15.2^{0}C; in 2004 - 15.3^{0}C and 13.4^{0}C in 2014 (the minimum values for the entire observation period under consideration); in 2008 - 15.4^{0}C and 15.9^{0}C (maximum values for the entire period under review). The curve in Figure 5 does not show such significant discrepancies for the corresponding value, nevertheless demonstrating a clear similarity in the extreme events of 2003, 2010, 2015, and other years of observations. These discrepancies can probably explained by the more complex nature of the impact of climate systems on the final values of the quantity under study. Other characteristic explanations for these discrepancies are also possible. From the analysis of the data, it can be seen that 2007 and 2013 are extreme in terms of the variability of the average annual temperature observed from satellites.

Which characterize the thermal features of the Caspian Sea observed from satellites for some model representations. The fact is that during a separate day it is possible to receive information on the same territory from several orbits of NOAA satellites. The corresponding territories can be covered during separate revolutions by clouds or be free from it. When presenting the final information product in the form of average monthly values, some of the corresponding scenes are inevitably "burdened" by the presence of cloud cover, while the other part may not contain clouds. It can be seen that the average annual values of the water surface temperature with a cloudless sky for individual years differ little from the similar curves in Figure 5. The maximum of these deviations is again noticeable for the territory of Azerbaijan (absolute value is about 14.9 °C) followed by a fairly even course of the corresponding values of about 14.9 °C for the rest of the observation years. Even more unexpected is the appearance of the maximum of these deviations for the entire Caspian region (its absolute value reaches 15.8 °C) with a subsequent fairly smooth course near 15 °C for the rest of the observation years. It is possible that these incomprehensible things are related to the small amount of sample data in the territory under consideration. The data are similar to the data in Figure 5, but characterize the values of the absorbed solar radiation flux by the "earth's surface-atmosphere" system. Again, one can note a fairly monotonous course of the annual values illustrated in Figure 5 at the top of the values for the selected region with maxima in 2007-2013 (about 15.3 - 15,5 °C) in 2003-2015 year.

These data characterize the thermal features of the Caspian Sea observed from satellites for some model representations. The fact is that during a separate day it is possible to receive information on the same territory from several orbits of NOAA satellites (in reality, up to four orbits from two simultaneously functioning satellites). The corresponding territories can be covered during separate revolutions by clouds or be free from it. When presenting the final information product in the form of average monthly values, some of the corresponding scenes are inevitably "burdened" by the presence of cloud cover, and the other part does not contain clouds [11]. The analysis of the available archives of satellite observation data of the Caspian Sea showed the characteristic features of the interannual values of the corresponding value for 14 years of observations (2001 - 2015). The results obtained showed statistical patterns in the behavior of the studied quantity, but also introduced uncertainties into some results of the interpretation of the available data (Table 4). These are the first results of such studies of the total set of parameters characterizing the state and variability of the biosphere and climate of the selected region. The basis for further research in this direction should be the study of the criteria for the statistical significance of the results obtained [12].

The work we carried out confirmed the correctness of the proposed methodological approach and the main starting points for organizing experimental satellite monitoring of the content of organic suspended matter in the surface waters of the Caspian Sea and the temperature fields of the sea surface:

- using a set of selected features, it is possible to decipher zones of high content of organic suspended matter, including oil films, in surface waters;
- the use of an algorithm for taking into account the influence of the atmosphere makes it possible to reduce both geographical due to shallow water and meteorological due to taking into account the distorting influence of aerosol formations, limitations in deciphering satellite spectrozonal information;
- the choice of NOAA satellites as a satellite platform for operational background monitoring of the sea surface and TERRA, ERS as platforms for occasional surveys in existing conditions is the only possible one in case of extreme situations.

4. Conclusion

In the work, an analysis was carried out on the basis of the available SST values of the Caspian Sea in order to develop a further methodology for collecting and analyzing satellite data. As a result of the studies performed, the possibility of operational monitoring of the state of the studied values of SST and Aorg over the entire water area of the Caspian Sea was shown.

The data obtained from the NOAA series satellites improve the ability to consider the re-analysis of the average annual values of the characteristics of the water surface temperature intensities. In specially selected areas of a retrospective review of the conditions that have developed over a certain period of time. The resolution of satellite information and the adopted processing techniques make it possible to reconstruct the picture of the spatiotemporal variability of the indicated quantities with the degree of detail that only cloudy conditions allow.

These studies further consider the atmosphere-sea system, which is necessary in solving the problems associated with the environmental problems of the Caspian Sea. Obviously, other means of observation, except for artificial satellites of the earth, are not even able to come close to the achieved indicators. At the same time, the data prepared by US and European specialists and published on the Internet are characterized by insufficient detail and methodological shortcomings due to the global nature of the information provided. The method proposed by the authors for monitoring the marine area can be actually tested and reasonably used only after control satellite observations have been made.

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Author contributions

Ismayil Zeynalov: Conceptualization, Methodology, Software **Rena Akhmedova:** Writing-Reviewing and Editing, Methodology, Software **Aybeniz Akhmedova:** Data curation, Writing-Original draft preparation, Software **Almaz Rustamova:** Visualization, Investigation, Validation

Conflicts of interest

The authors declare no conflicts of interest.

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