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OVERVIEW OF REMOTE SENSING DATA ON WAVE PROCESSES IN THE KAZAKH PART OF THE CASPIAN SEA

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The Caspian Sea is an inland body of water subject to various hydrometeorological phenomena and, in particular, wind waves. The development of observation methods and data processing currently makes it possible to study wind waves in the open water area of the sea. This paper presents a review of remote sensing data, in which the characteristics of wind waves are presented. According to RS data, the maximum wave height is observed in the Middle Caspian Sea. The highest values of the maximum wave height were observed in different periods of the year, however, in the cold period their number prevailed.

Keywords: Caspian Sea, wind wave, ECWAM, wave height, wave direction

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INTRODUCTION

The Caspian Sea is the world's largest water body with which the economic, transportation, infrastructure and tourism plans of the Caspian littoral countries (Russia, Kazakhstan, Turkmenistan, Iran, Azerbaijan) are connected (The Sea Project, 1992).

Works carried out in the open water area of the sea, on its shelf and coastal part are exposed to the influence of various hydrometeorological phenomena, including short-period sea level changes, storm winds, high waves etc.

Wind waves is one of the main hydrometeorological factors determining the safety and economic efficiency of navigation. In turn, the wave processes considered in this paper have a negative impact on navigation, cause coastal reshaping, in this regard, the analysis of wave data, forecasting its characteristics are important tasks to ensure safety at sea.

In the Kazakhstan part of the Caspian Sea under consideration, observations of wave processes are carried out visually; therefore, in most cases, wave characteristics in the open part of the sea and in some of its areas are determined through the analysis of remote sensing data, as well as modeling of processes.

The purpose of this work is to study wave characteristics in the Kazakhstan sector of the Caspian Sea using remote sensing data.

According to the research of Lebedev S.A., Kostyanoy A.G., Ginzburg A.I., modern methods of numerical modeling, their development, and an increase in the amount of remote sensing data make it possible to accurately analyze dynamic processes occurring in the Caspian Sea (Lavrova and et.all, 2011), including wave processes.

Identification of the main features of the wave climate of the Caspian Sea according to the NCEP/NCAR reanalysis, its retrospective analysis was performed by Lopatukhin L.I., Yaytskaya N.A. (Yaitskaya, 2017; Lopatukhin and Yaitskaya, 2019a; Lopatukhin and Yaitskaya, 2019b), Myslenkov S.A. (Myslenkov and et.all, 2018).

Bruneau N., Tommi R (Bruneau and Tommi, 2016) the wave calculations were carried out using a conjugate system using WRF, ROMS, SWAN. According to them, multimode wave states are observed in the Caspian Sea. Rusu E., Onea F. (Rusu and Onea, 2013) wave characteristics were modeled using the ERA-Interim wind reanalysis for 2005-2010, the result of which showed that the maximum wave heights are formed in the Middle part of the sea.

A number of authors have written about the applicability of satellite altimeter data (Cazenave and et.all, 1997), including the results of Kazakhstan authors Rakisheva Z.B., Kudryavtseva N., Kusembayeva

K.K., Sakhaeva A.K. (Rakisheva and et all., 2019; Kudryavtseva and et all, 2019). Increasing the accuracy of altimetric measurements and the development of new methods of their processing lead to the possibility of using remote sensing data not only in the oceans, but also in inland waters (Lebedev, 2014; Lebedev, 2011; Lebedev, 2013; Lebedev and Kostianoy, 2006a, Lebedev and Kostianoy, 2006b).

According to the zoning map of the average wave height for the period 1993-2012 over the entire waters of the Caspian Sea, developed by Lebedev S.A. (Lebedev, 2014) according to altimeter satellites, it was found that the western coast of the Middle Caspian and the southeastern part of the Southern Caspian are affected by the greatest heights during wind waves. It is also noted that in the Middle Caspian Sea, wind waves with a height of more than 2 m are observed in January and October (Lebedev, 2013; Lebedev and Kostianoy, 2006b; Lebedev and Kostianoy, 2008).

MATERIALS AND METHODS

RSE «Kazhydromet» conducts visual observations of wave characteristics at 7 sea stations and posts: Kulaly Island, Fort-Shevchenko, Saura, Aktau, Fetisovo, Kuryk, Peschanyi (Isan). The maximum observed wave heights were up to 4.5 m (two cases: Aktau 1985, Peschanyi 2009). According to coastal observations, waves with heights of more than 2 m are recorded at all locations (Eltay et al., 2019), and it is rather difficult to distinguish the years with more active wave processes, as significant waves were recorded in each year under study.

The location coordinates, period of wave observation, and total number of observations analyzed are given in table 1.

Table 1

The number of cases of wind waves of different heights

Station	Coordinates		Period of observations	Total number of analyzed data	Number of cases with wave height in the interval, m			
	Lat.	Long.			0,75-1,25	1,25-2	2-3,5	3,5-6
Kulaly Island	45.01	50.02	2001–2022	26771	3881	594	9	
Fort-Shevchenko	44.33	50.15	1993–2022	33475	1027	214	1	
Saura	44.19	50.48	2010–2022	19174	3141	1485	7	
Aktau	43.6	51.22	1980–2022	23493	1177	444	74	1
Peschanyi (Isan)	43.11	51.16	2009–2022	19292	2946	1128	41	1
Kuryk	44.56	50.59	2009–2022	17413	453	23		
Fetisovo	42.49	52.35	2006–2022	22126	209	12		

Analysis of data on coastal stations and posts showed that the highest wave heights were observed in the Middle Caspian Sea at Aktau and Peschanyi (Table 1). Also at Kulaly Island, located far from the coast, significant waves with a height of more than 0.75 m are more often recorded, which confirms that the wind is the determining factor of the waves in the open water area of the reservoir. The wind wave regime is determined mainly by the distribution of speed and direction of prevailing winds. In the Kazakhstan sector of the sea for the period 1980-2022, strong waves equal to or higher than 2 m were observed 132 times. The prevailing excitement is of the western direction, the frequency of which for the period under study amounted to 30%. Of the other wave directions, the northwestern and southeastern directions should be noted, the frequency of occurrence of which amounted to 26 % and 25 %, respectively.

However, the data of instrumental observations provide an opportunity to analyze only small areas, therefore a review of remote sensing data in the open sea area was made.

Various data now exist, including satellite altimeter data, reanalyses, etc.

Altimeter data.

Since the beginning of 1990, the number of observations from Earth satellites has increased, especially the development of satellite altimetry measurements began (Lebedev, 2015; Mizyayuk, Korotayev, 2019).

Satellite altimetry is the measurement of satellite altitude relative to the Earth's surface by the transit time of the signal sent and received after reflection from the surface by the satellite (Soomere, Keevallik, 2011). The main feature of altimeter measurements is that cloud cover does not affect the measurements, and the data are homogeneous both in spatial distribution and regular in time (Open Altimeter Database, 2021; The Radar Altimeter Database System, 2021; AVISO, 2021; Jet Propulsion Laboratory, 2021).

The altimeter emits a radar wave and analyzes the response signal, which is reflected from the surface. The surface altitude is the difference between the position of the satellite in orbit relative to an arbitrary reference surface (the center of the Earth or a rough approximation of the Earth's surface: a reference ellipsoid) and the distance from the satellite to the surface (calculated by measuring the time for the signal to make the round trip). In addition to surface height, wave height and wind speed over large bodies of water, backscatter coefficient and surface roughness can also be measured.

Altimetric measurements are carried out along sub-satellite traces (tracks) that uniformly cover the study area. Iso-route programs assume repeatability of tracks within ±1 km after a certain time cycle.

There are various archives and databases of altimeters (altimeters) (Table 2), in this paper we used wave height data from RADS data developed by DEOS within the Netherlands Observatory NETWOW NEONET (The Radar Altimeter Database System, 2021). A distinctive feature of RADS is the availability of data directly over the Caspian Sea water area.

Table 2

Satellite altimeter databases

Title	Data/products	Format
OpenADB (Open Altimeter Database, 2021)	Sea surface height, sea level anomalies, instantaneous dynamic ocean topography, empirical ocean tide model, vertical total electron content, adaptive leading edge subwave retracker.	netcdf
RADS (The Radar Altimeter Database System, 2021)	Sea level anomaly, significant wave height, reflection coefficient, wind speed	ASCII
Aviso+ (AVISO, 2021)	Sea level anomalies, significant sea level elevation, wind and wave data, etc.	netcdf
Podaac (Jet Propulsion Laboratory, 2021)	Data on ocean characteristics, glaciers, ocean swell, etc.	netcdf
STAR (STAR, 2021)	Significant wave height	png, jpeg

RADS presents wave height values from satellites with altimeters or altimeters: ERS-2, ENVISAT, TOPEX, Jason-1, Jason-2, Cryosat-2, Saral, Sentinal-3 for different periods of their observations (Figure 1).

Data from ECWAM models.

The ECWAM ocean wave model, using the ERA5 reanalysis-based ECWAM, generates wave characterization data. The ocean wave model (ECWAM) describes the development and evolution of wind-generated surface waves, as well as their height, direction and period (Scharroo and et al., 2012).

The model is coupled to the atmospheric forecast in all configurations (HRES, ENS, Extended Range, Seasonal) produced by ECSPP and the NEMO ocean dynamical model.

The significant wave height of the reanalysis data represents the distance between the trough and the crest.

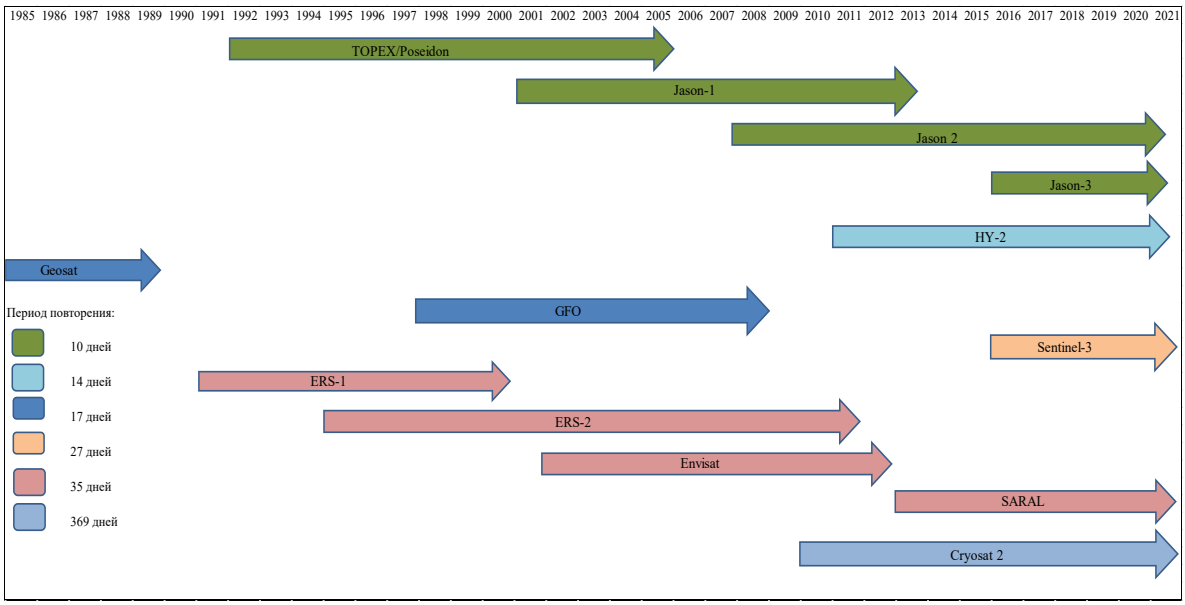

Fig.1. Altimeter satellite missions

However, there are many waves at the ocean surface and their distribution is determined by the two-dimensional wave spectrum. Based on this distribution, the significant wave height is defined as the square root of the integral over the frequency and direction of the wave spectrum multiplied by 4. It can be shown to correspond to the mean height of one-third of the highest waves, usually known as H1/3. The mean wave direction is the spectrally averaged direction of wave propagation (amplitude weighted) (Ocean Wave Model, 2021).

The values of wind wave characteristics were obtained from the Climate Data Store for the period 1959...2022 using hourly data in netCDF format for individual months based on the ERA5 reanalysis with a spatial resolution of 10*10.

RESULTS AND DISCUSSION

Figure 2 shows the graph of change in the average value of significant wave height for the Caspian Sea water area for the period 2002...2022. The average wave height for 2002...2022 was 1.31 m. The highest values of the mean annual wave height were observed in the period 2011...2015, with the maximum mean value of 1.75 m in 2011.

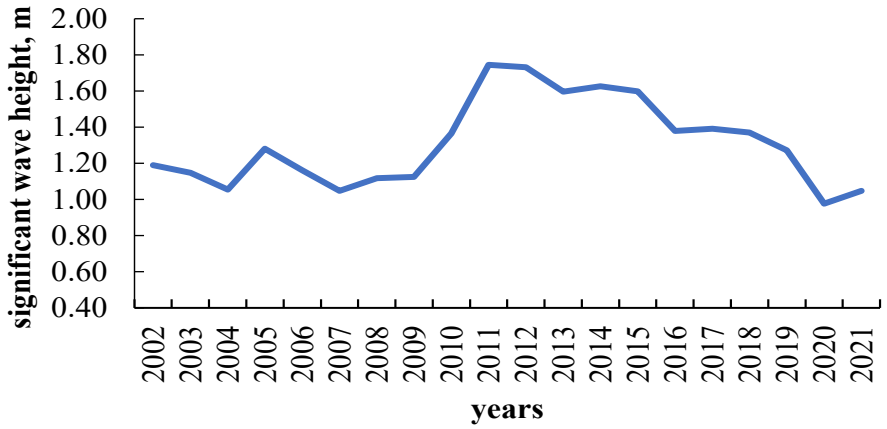

Fig.2. *Plot of the course of significant wave height from altimeter data*

The intra-annual distribution of significant wave height from 2002 to 2022 shows that the highest values are observed in the cold period of the year (October-March). The maximum in January with a gradual decrease in May-July and further increase by December. Thus, the highest average value was observed in February 2012, equal to 2.43 meters.

By seasons of the year, the average values of significant wave height were in winter - 1.56 m, in spring - 1.21 m, in summer - 1.14 m, and in fall - 1.36 m. The maximum values of wave height were: in winter 2.19 m, in spring 1.86 m, in summer 1.59 m, in fall 1.84 m.

Based on ECWAM model data, maps of changes in mean wave height during wind-driven waves were constructed for 1959...2021 (Figure 3). The average values ranged from 0.1...1.0 m, the maximum from 0.3 m to 3.6 m, and the minimum 0.03...0.25 m. The highest mean and maximum wave height values are distributed in the open water area of the Middle Caspian Sea, covering the entire Kazakhstan part of the eastern Caspian Sea. The maximum wave height values are observed in March (up to 2.88 m), December (up to 2.59 m) and October (up to 2.07 m). The lowest value of the maximum wave height is noted in July, equal to 1.19 m.

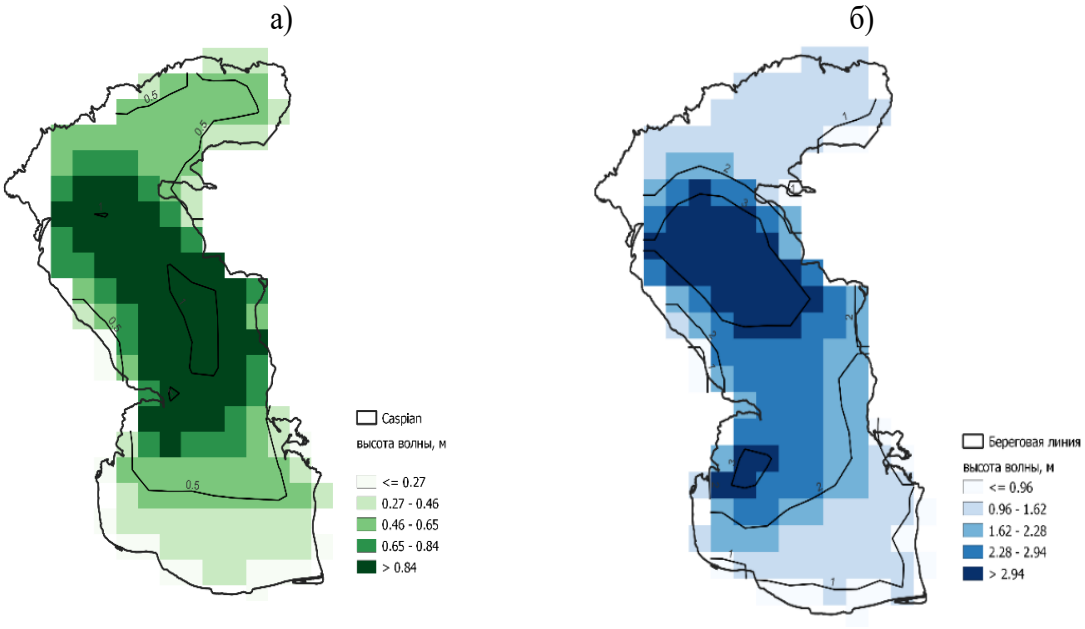

Fig.3. *Maps of distribution of significant wave height in the Caspian Sea water area for 1959...2021 a) average, b) maximum*

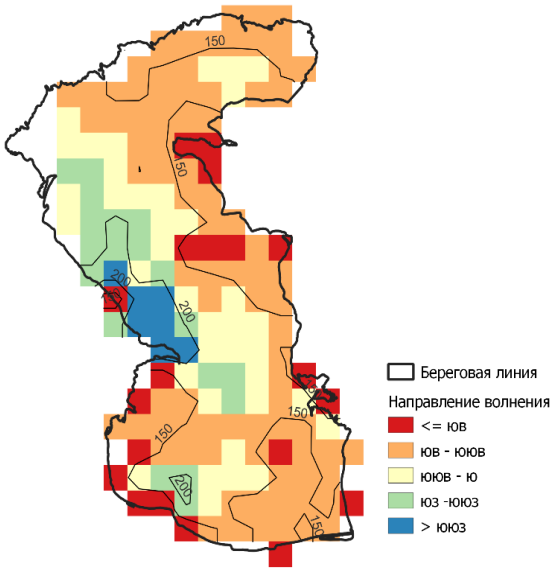

Fig.4. *Distribution maps of the prevailing direction of significant wave height in the Caspian Sea water area for 1959...2021*

The ECWAM modeled data on wind waves in the Caspian Sea show that the predominant directions are south, southeast and southwest (Figure 4). For the Kazakhstan sector of the sea, the prevailing wind wave directions are also south and southeast.

Intra-annual section shows that the average direction of wind waves in the Kazakhstan part in January, April, November is southeast, in February, September - southeast and southwest, in March - southeast, east, May - northeast, east, southeast, in June - northeast, east, July - northeast, south, in August - northeast, northwest, southeast, in October - southwest, west, in December - south.

The mean wind wave period for 1959-2022 ranged from 2.6 s to 4.0 s (Figure 5), with maximum values ranging from 3...7 s and minimum values ranging from 2...3 s. According to the calculated data of the ECWAM model, the highest values of the mean wind wave period were in March, August and December.

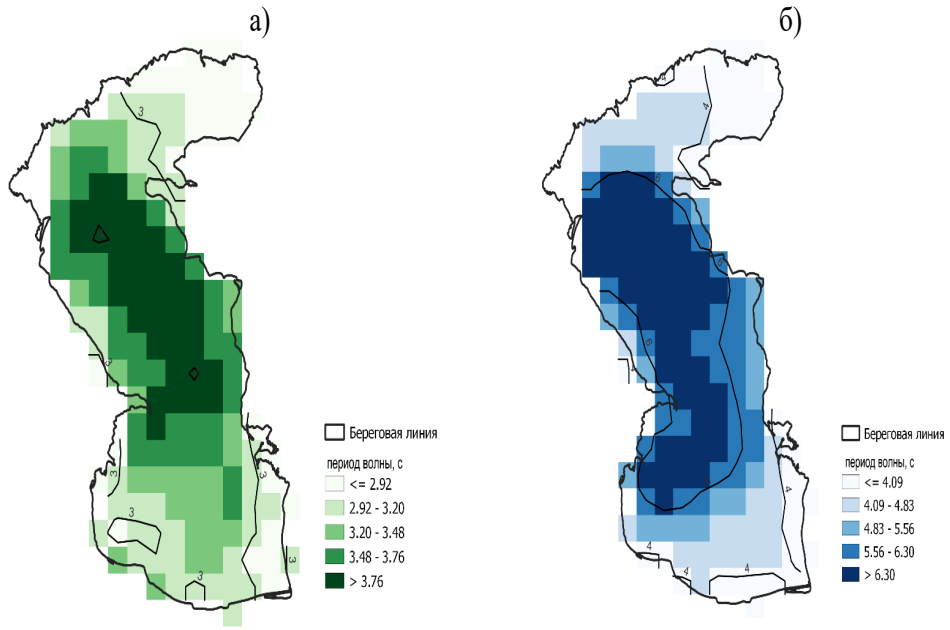

Fig.5. *Maps of wave period distribution in the Caspian Sea water area for 1959...2021 a) average, b) maximum*

CONCLUSION

The coast of the Caspian Sea belongs to the region that is subject to environmental crisis, primarily related to the fall or rise in sea level. The dynamism of the atmosphere predetermines the possibility of storm events at sea. Strong waves and winds can lead to loss of control of vessels, which may result in accidents when vessels collide with the platform or sink. I n this regard, the study of wind wave characteristics in the open water area of the sea plays an important role in conducting safe operations at sea. At present, the development of technology and data processing methods allow obtaining data on wind waves in the open water area of the Caspian Sea, primarily based on remote sensing data considered in this paper.

According to the analyzed data (coastal observations, altimeter satellite data, modeled ECWAM data), it can be seen that the maximum wave height is observed in the Middle Caspian Sea. The highest values of maximum wave height were observed in different periods of the year, but their number prevailed in the cold period, which is due to the fact that the highest average wind speeds are also observed during the period under consideration.

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КАСПИЙ ТЕҢІЗІНІҢ ҚАЗАҚСТАНДЫҚ БӨЛІГІНДЕГІ ТОЛҚЫНДЫҚ ПРОЦЕСТЕР ТУРАЛЫ ҚАШЫҚТЫҚТАН ЗОНДЫЛАУ ДЕРЕКТЕРІНЕ ШОЛУ

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Каспий теңізі – әртүрлі гидрометеорологиялық құбылыстарға, атап айтқанда жел толқындарына ұшырайтын ішкі су айдыны. Қазіргі уақытта бақылау әдістері мен мәліметтерді өңдеудің дамуы жел толқындарын ашық теңізде зерттеуге мүмкіндік береді. Бұл жұмыс жел толқындарының сипаттамаларын көрсететін қашықтықтан зондылау деректеріне шолуды ұсынады. Қашықтықтан зондтау деректері бойынша толқынның максималды биіктігі Орталық Каспий теңізінде байқалады. Толқынның максималды биіктігінің ең жоғары мәндері жылдың әртүрлі кезеңдерінде байқалды, бірақ суық кезеңде олардың саны басым болды.

Түйін сөздер: Каспий теңізі, жел толқындары, ECWAM, толқын биіктігі, толқын бағыты

ОБЗОР ДАННЫХ ДЗЗ О ВОЛНОВЫХ ПРОЦЕССАХ КАЗАХСТАНСКОЙ ЧАСТИ КАСПИЙСКОГО МОРЯ

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Каспийское море является внутренним водоемом, подверженным различным гидрометеорологическим явлениям и, в частности, ветровому волнению. Развитие методов наблюдений и обработки данных в настоящее время дают возможность исследования ветрового волнения на открытой акватории моря. В данной работе представлен обзор данных ДЗЗ, в которых представлены характеристики ветрового волнения. Согласно данным ДЗЗ максимальная высота волны наблюдается в Среднем Каспии. Наибольшие значения максимальной высоты волны наблюдались в различные периоды года, однако в холодный период их количество преобладало.

Ключевые слова: Каспийское море, ветровое волнение, ECWAM, высота волны, направление волнения