ФІЗИЧНА ГЕОГРАФІЯ

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ICE REGIME IMPACT ON THE COASTAL ZONE OF THE AZOV SEA

Azov is freezing sea it means that forecast of the time of the beginning and the end of ice fields formation needs. The ice condition limited of maritime safety. Modern condition of ice regime in the Azov Sea has been considered. The navigation of the Ukrainian ports Berdjansk and Mariupol depends on ice regime, duration and ice cover thickness. For the passage of vessels along the sea approach channels and recommended courses in the winter, the use of icebreakers is required. The demolition of confining buoys by ice fields and their restoration is reflected in the economic opportunities of the ports.

Purpose of the article is to establish the characteristic winter periods of the last decade, taking into account the climatic changes for the rational using of the results of the impact on the economic activity of the marine infrastructure and hydrographic services. The specific purpose of this publication is to evaluate the displacement of the means of navigation equipment – buoys in the winter, taking into account meteorological factors. The authors set the following tasks: 1) to identify periods and vectors of buoys; 2) to define wind and ice characteristics in separate periods; 3) to reveal the basic meteorological cause of the movement of the buoys. It is important to note that there are no similar publications concerning this region. It became very actual after the climate change period was marked.

The reserach is based on the data of direct and remote observations, the dates of ice formation in the area of seaports of Ukraine (Berdyansk and Mariupol) the characteristics of ice, the end of freezing, the opening and clearing of ice from the water areas of ports and bays and using the information from NAVTEX warning system, the archival materials of the weather site meteo.ua. The features of the physicochemical properties of sea water during ice formation and the general circulation of the waters of the Azov Sea are examined, which is linked with the influence of fresh runoff of Don and Kuban rivers. In the period 2013–2021 the observations were made on the displacement of navigation aids (buoys) during the winter periods from the approach channels of the port of Mariupol and Berdjansk as well as noticed buoys from the Azov-Don Marine Channel (Russian Federation).

The characteristic of winter periods and conditions during the last decade are considered taking into account the influence of climatic changes. It is noted that the ice regime of the Sea of Azov is closely related with the sum of average daily air tem-

peratures over the sea for the season and wind power. According to this criterion, winters are usually divided into three types: severe, moderate and mild. Over the past 30 years, there were only two severe winters in the Azov Sea in 2005–2006 and 2011–2012. During these winters, the Azov Sea was completely ice covered. The influence of the ice regime to the coastal zone was examined, because it is very important for the industrial and economic needs of state building. To maintain the safety of navigation and reduce economic losses, it is necessary to consider the possibility of removing buoys, which are most often displaced by ice drift. Long-term average observations indicate the beginning of ice formation in Mariupol on December 14, and in Berdyansk on December 20. The Taganrog Bay and the ice accumulation areas are cleared of ice most recently – March 20–28. Under modern climatic changes (increasing the frequency of mild winters, actual costs for the operation of ships, hydrographic, icebreakers, etc.) are expected to be an order of magnitude lower than standard indicators.

Keywords: Azov Sea, modern ice conditions, climate change, port's water areas, approach channel.

INTRODUCTION

Azov is freezing sea it means that forecast of the time of the beginning and the end of ice fields formation needs. The ice condition limited of maritime safety. Modern condition of ice regime in the Azov Sea has been considered. The safety of navigation of the Ukrainian ports Berdjansk and Mariupol depends on ice regime, duration and ice cover power. For the passage of vessels along the sea approach channels and recommended courses in the winter, the use of icebreakers is required. The demolition of confining buoys by ice fields and their restoration is reflected in the economic opportunities of the ports. The aim of this work is to improve the safety of navigation in winter conditions.

The problem is to identify the characteristic winter periods of the last decade, taking into account climatic changes, for the rational using of the results for the economic growth of maritime infrastructure.

The ice regime problem and the effect of ice cover in the Sea of Azov on shipping is not often discussed, but is discussed in national and Russian publications. In Ukraine, since 2009, ice campaigns of the northern part of the Sea of Azov are most often considered in works (Gavry`lyuk, & Yuvchenko, 2019; Kulik, 2019; *Ice situation,* 2019; Savter, 2014). In recent years, climatic conditions in the Azov Sea region have been changing, including the absence of ice cover in 2015–2020 except for a short period in January 2019 that restricts shipping.

At the same time the ice condition in the Sea of Azov sometimes is quite complicated, and it is the reason for limited shipping, adversely affecting to operate of navigation equipment (buoys, sea approach channels, etc.) and often needs to use the icebreaker. The water area located in the northern part the Azov Sea had been considered in the paper. The main tasks of the paper are to make the considering and analyzing the modern ice regime and its impact on shipping, taking into account the of climatic factors trends development.

DATA & METHODS

The direct data set and remote observations of the drift of buoys under the influence of ice cover were used. For a modern assessment of the impact of ice cover on shipping, the indicators as the frequency of ice campaigns in the ports of Ukraine; characteristics of periods of freezing and clearing of ice; observation of the displacement of marine navigation buoys were used.

Among the ice regime characteristics, the dates of ice occurrence in the area of seaports of Ukraine (Berdyansk and Mariupol) completion of freezing, opening and clearing of ice from port and bay water areas, information from the NAVTEX warning system archival materials of the meteo.ua weather site were also using.

It is important that the current ice regime differs significantly from that previously described in navigational aids, sailing directions, available publications and hydrometeorological atlases (Chepurna, 2018; *Pilot of the Sea*, 1985; Lysyy, 2015; *The project*, 1991).

The analyses of the features physic-chemical properties of seawater during the ice formation and general circulation of the waters of the Sea of Azov that linked with modern value of the fresh water runoff of the main rivers Don and Kuban was also done.

The relevance of the study of the influence of the ice regime on the coastal zone of the Azov Sea occurs now in many aspects, as an example, in modern times, on the basis of the research basin of the Sea Institute, the rare natural phenomenon of the Ice River, which occurs in the area of the appropriate coal harbor of the port of Mariupol near the feet buoys № 8 and № 6 (Nesterov, Zagorodnya, & Perepechayev, 2021).

RESULTS

In winter time and early spring, all maritime services and the fleet operate are under in ice conditions; the coastal zone is affected by ice. The freezing processes of marine and fresh water are not the same due to differences of their chemical and physical properties. Because of the desalinated water formatted by the Don river input to the Taganrog Bay the highest relative density of water here is 4 °C and freezes at low temperatures (slightly below 0 °C), in the freshwater basin, after the water cools to 4 °C, further cooling of its surface layer proceeds very quickly. So, the water here becomes lighter than the underlying water, which eliminates mixing, and therefore, the rising to the surface of warmer water masses from the deep layers. Ice formed by fresh water is a homogeneous mass of ice crystals, in which air bubbles and various solid particles in water are interspersed (Stekhnovskiy, & Zubkov, 1977).

The low salinity of the Azov Sea, that is formed as a result of the influence of two big rivers – Don and Kuban (sources of freshwater runoff), ice can occur from late November to early December. The increase in ice thickness in the Sea of Azov occurs unevenly during the winters depends on different weather conditions. In the

shallow water area and low water salinity (see Fig. 1), the first ice is formed in the area of Primorsko-Akhtarsk and near the village of Achuyevo, after 7–10 days ice still covers the Taganrog Bay, Utlyuk and Akhtarsky estuaries area and part of the Yasen Bay.

At the same time, a fast ice band is formed along the northern coast of the sea, at the edge of which the amount of drifting ice is noticeably increasing (Chepurna, 2018).

The port of Mariupol, located in the Taganrog Bay, is under the influence of the river Don with river mouth is located about 100 km from. The variability of salinity in this area is from 7 to 11‰.

The annual river runoff of the Don is about 21 km^3 per year, that is about 50% from the total continental runoff to the sea. According to investigations of the Azov Research Institute of Fisheries, the annual river runoff of the river Kuban, at present, has even exceeded the runoff of the Don (*Don lost*, 2019; Kosenko, Baskakova, & Kartamysheva, 2018).

However, according to the general circulation of the Azov Sea, the transfer of the desalinated waters of the Kuban to the Taganrog Bay does not occur. In recent years, there has been a trend of milder ice conditions in the Sea of Azov.

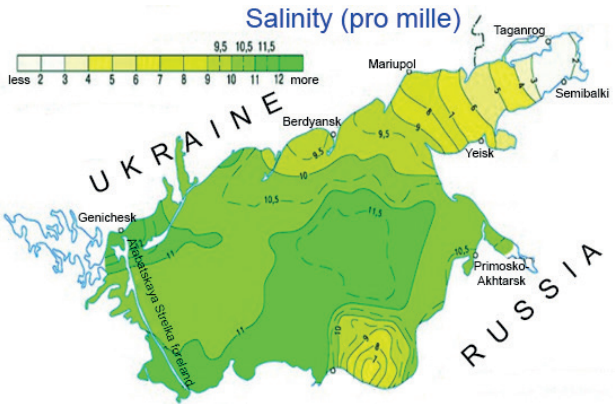


Fig. 1. Distribution (Spring average data) of water salinity (‰) in the Sea of Azov. Scale 1:3 500 000 (Kulik, 2019)

In the period of 2013–2021 the observations were made on the displacement of navigation aids (buoys) during the winter periods in the approach channels of the port of Mariupol and Berdyansk (Table 1).

Low air temperatures remained for a long time, and at the same time there was an extremely unfavorable strong east wind (up to 32 m/s). The entire water area of the Sea of Azov was covered by a continuous impenetrable ice field. The thickness of the ice reached 70 cm, and in hummocks up to 3.5 m, severe frosts and winds led to icing of the ships.

Table 1

Winter displacement of buoys from approach channels of the port of Mariupol and Berdyansk

NN	The number of buoy	Coordinates of buoy	Time of disappear	Time of find out	The coordinates of discovered buoy
1	*2*	*3*	*4*	*5*	*6*
1	№ 15 approach channel of Mariupol Port (Mariupol)	47°01.3N 37°29.8E	Winter 2011—2012	Not found	
2	№ 16 Mariupol	47°01.3N 37°29.7E	Winter 2011—2012	Not found	
3	№ 1 Mariupol	46°53.8N 37°27.4E	14/01/2013	Not found	
4	№ 2 Mariupol	46°53.7N 37°27.3E	14/01/2013	Not found	
5	№ 12 Mariupol	46°59.3N 37°29.0E	14/01/2013	Not found	
6	№ 22 approach channel of Berdjansk Port (Berdjansk)	46°44.9N 36°46.1E	09/01/2013	Not found	
7	№ 1 Mariupol	46°53.8N 37°27.4E	21/03/2014	Not found	
8	№ 4 Berdjansk	46°37.6N 36°36.9E	15/02/2014	Not found	
9	№ 8 Berdjansk	46°39.2N 36°39.0E			46°29’0.00"N36°29’5.00"N
10	№ 1 Berdjansk	46°36.7N 36°35.9E			46°37’0.00"N36°44’7.00"E
11	№ 16 Berdjansk	46°42.4N 36°43.1E	04/2017	05/2017	46°44’7.00"N36°37’0.00"E
12	№ 12 Berdjansk	46°40.8N 36°41.0E			46°41’27.00"N36°37’23.00"E
13	№ 6 Berdjansk	46° 38.4N 36° 38.0E	21/02/2018		46°41’44.00"N36°27’4.00"E
14	№ 10 Berdjansk	46°40.0N 36°40.0E			46°41’2.00"N36°30’22.00"E
15	№ 9 approach channel of Rostov port (Rostov)	47°02’C 38°58’E		02/11/2017	46°55’44.16"N37°17’46.36"E
16	№ 1 Mariupol				1 mile to SW 46°29’0.00"N36°29’5.00"E
17	№ 1 Mariupol	46°53.8N 37°27.4E	03/02/2018	05/02/2018	46°52’54.00"N7°20’3.00"E
18	landfill buoy Mariupol	46°59’17.20"N 37°27’30.21"E	08.05.2018	09/05/2018	46°58’41.5704"N37°25’43.1578"E
19	landfill buoy Mariupol	46°58.0 N 37°26.8 E	03.12.2018	12/12/2018	Tentatively 46°56’18"N 37°23’03"E

Table 1 (continuing)

1	*2*	*3*	*4*	*5*	*6*
20	Buoy of Russian Federation			03.12.2020	46°57’44"N 37°24’34"E
21	Buoy of Russian Federation			24.12.2020	46°50’7.20"N 37°11’59.40"E
22	Buoy of Russian Federation			10.02.2021	46°43’7.52"N 36°50’25.12"E
23	№ 1 Berdjansk	46–36.7 N 036–35.9 E	01.03.2021		Initially – N-NE to 400 m After ice leaving – 46°33’24.00"N 36°38’0.60"E
24	№ 18 Berdjansk	46–43.3 N 036–44.1 E	20.01.2021		Initially – SW to 300 m After ice leaving – 46°42’15.60"N 36°36’25.20"E
25	№ 20 Berdjansk	46–42.4 N 036–43.1 E	25.02.2021	30.04.2021	46°42’36.00"N 36°31’58.80"E
26	№ 16 Berdjansk	46–42.4 N 036–43.1 E	25.02.2021		
27	№ 22 Berdjansk	46–42.4 N 036–43.1 E	25.02.2021		

Their movement along the shipping channels, from the Azov Sea to the Kerch Strait took place in difficult conditions.

Buoys were found, without the ability to identify their number and affiliation, in the following coordinates (Table 2).

As a result of analyzing of the announcements from 2012 about of ice companies in the port of Mariupol, the following chronology was obtained:

Ice regime during 2011–2012 was extremely severe (Fig. 2).

Their movement along the shipping channels, from the Azov Sea to the Kerch Strait took place in difficult conditions.

12/18/2012 – the beginning of the ice company. The thickness of the ice in the water area and on the approach channel is 10–20 cm.

02/15/2013 – the time of closing of ice navigation. The ice campaign was rated medium complexity because the thickness of the ice “in the virgin land” reached 25 cm, and in the places of hammocks it reached 150 cm (for example, in 2011–2012 the ice thickness reached 70 cm and the hummocks reached 350 cm) (*Mariupol commercial,* 2019).

01/28/2014 – the opening of an ice company in the port was announced. 02/05/2014 – icebreaking operations were resumed in the Sea of Azov and the Kerch Strait, which were not conducted from January 26 because the low water level in the ports and the Taganrog Bay. The ice layer in the Sea of Azov was about 10 cm, but the east wind carried ice to the water area of the ports from the Taganrog Bay and the thickness of hummocks reached 40 cm (fig. 3).

Table 2

Discovered unidentified buoys

NN	The number of buoy	The coordinates of discovered buoy
1	Not identified	46°18’24.6"C 35°20’25.20"B
2	Not identified	46°15’08.0"N35°49’06.0"E
3	Not identified	46°21’50.0"N36°49’08.0"E
4	Not identified	46°29’00.0"N36°29’36.0"E
5	Not identified	46°33’00.0"N36°30’00.0"E
6	Not identified	46°28’48.0"N36°35’18.0"E
7	Not identified	46°28’42.0"N36°35’00.0"E
8	Mileston Not identified	46°31’19.11"N36°09’15.90"E

Due to the ice situation in the Sea of Azov, the work of the ports of Mariupol and Berdjansk was complicated (*Ice situation in Azov,* 2019).

03/06/2014 – the ice campaign in the port of Mariupol is closed.

On 02/02/2015 – the ice campaign 2014–2015 did not start.

Ice Campaign 2015–2016 – did not start.

02/03/2017 – the beginning of the ice campaign in the Azov Sea has been announced. This is due to the fact that the thickness of the ice has reached 10 or more cm.

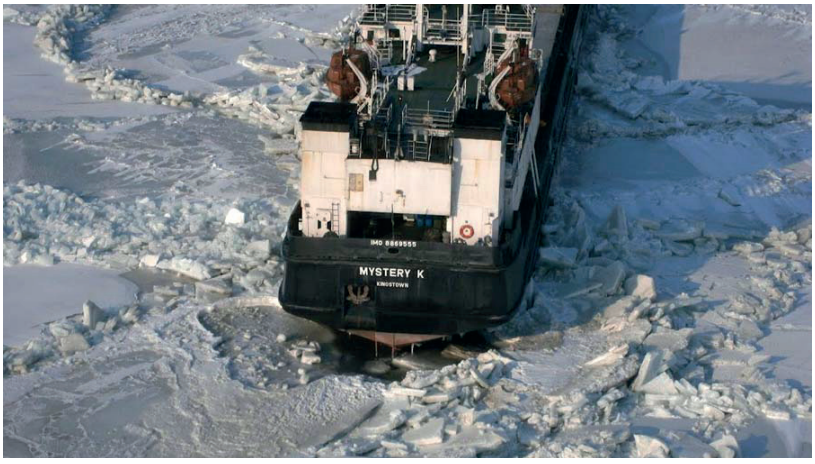


Fig. 2. In the ice of the western part of the Azov Sea, February 10, 2012. Photo of the helicopter crew of the airline “Universal Avis” (Ice situation, 2019)

During the 2016–2017 ice campaign, which lasted 25 days in the Mariupol Sea Port and the Azov Region, the only icebreaker in Ukraine carried out icebreaking escort of 21 vessels to the entrance and 23 to the exit from the sea ports of Mariupol and Berdjansk to the Kerch-Yenikalsky Canal and to reverse direction. Ice Campaign 2017–2018 – did not start 01/11/2019 – the headquarters of ice operations was created (an ice campaign in the port of Mariupol was not announced. According to the main dispatching administration of the Mariupol Sea Port, the port's water area is covered with fine ice, the initial types of ice are observed on the approach channel of the port from 0 km to 12 km, then clear water (*Ports of Ukraine*, 2020).

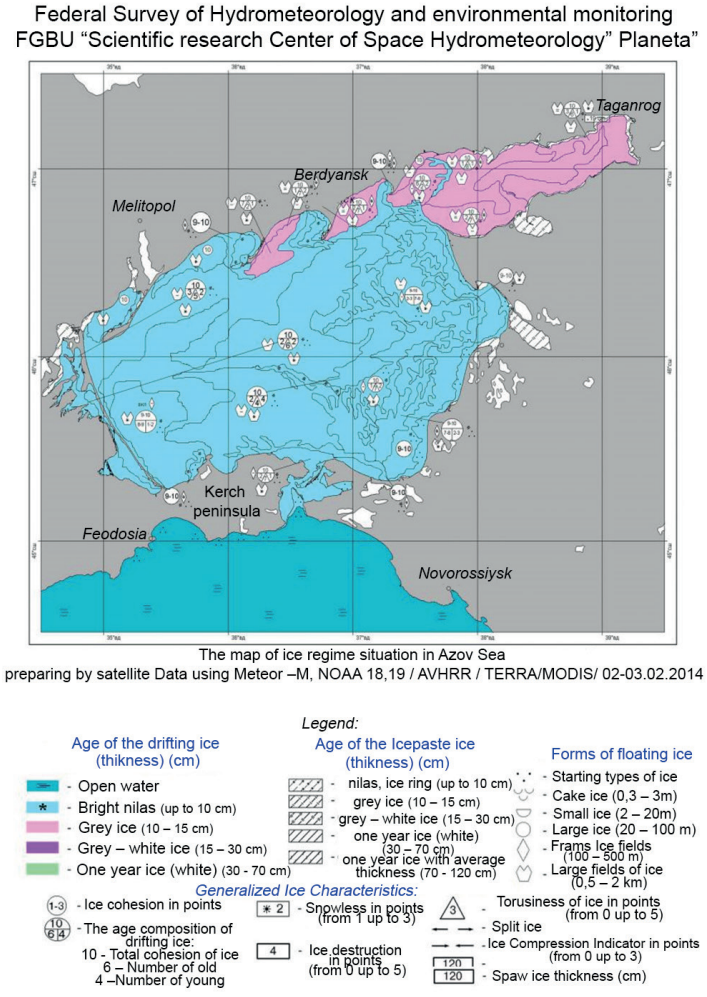


Fig. 3. Ice conditions in the Azov Sea 02/02/2014 (Ice situation, 2019)

Ice Campaign 2019/2020 (as of 02/09/2020) – did not start.

Ice Campaign 2019/2020 – did not start.

Analysis of individual buoy offsets:

The absence of buoy No. 16 of the Berdjansk port was discovered in March 2017 (standard coordinates 46°42’4.00N36°43’1.00’’E), when the water area of the bay was cleared of ice. In May 2017, buoy with number 16 was found at coordinates 46°44’7.00”C = 36°37’0.00”E. The displacement range is 8.3 km at the WNW.

According to the information of the ESIMO operational module “Ice conditions in the Azov Sea”, the following ice characteristics were obtained in the area of the buoy displacement:

01/23/07/2017 – nilas, ice ring. Partially on NE fast ice. Cohesion is 4–6 points. 02/13/2017 – nilas, ice ring. The total cohesion is 10 points, the predominance of young ice.

02/20/2017 – gray ice. The total cohesion of 10 points, the prevalence of old ice. 02/28/2017 – the beginning of the cleansing of the bay from ice. In the area of 16 buoy gray ice. The total cohesion of 10 points, the prevalence of old ice.

03/07/2017 – pure water.

According to the weather archive of the site meteo.ua and weather reports of the port of Mariupol, the following data were noted (average wind per day and the most repeated wind direction during the day) (Table 3).

Table 3

Medium wind (m/s) and most repeated wind direction (rumba)

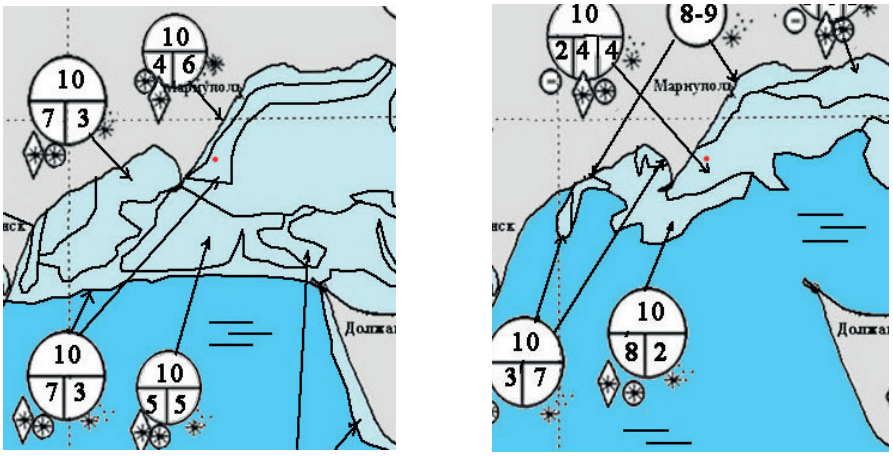
Port	**07/02/17**	**08/02/17**	**09/02/17**	**10/02/17**	**11/02/17**	**12/02/17**
Berdjansk (08:00)	7. E	11. E	8. ENE	5.NE	4. NE	4. N
Mariupol (07:00)	10. NE	13.E	9.NE	8.NE	6.N	7.N
	13/02/17	14/02/17	15/02/17	16/02/17	17/02/17	18/02/17
Berdjansk (08:00)	3.NW-N	4.W	8.N	5.N	2.S	3.SW
Mariupol (07:00)	1.N	4.W	10.NW	5.N	1.N	0
	19/02/17+	20/02/17+	21/02/17+	22/02/17+	23/02/17+	24/02/17+
Berdjuansk (08:00)	2.SW	2.NE	3.SW	6.W	7.W	3.SW
Mariupol (07:00)	2.SW	0	2.SW	8.SW	23.SW	0
	25/02/17	26/02/17	27/02/17	28/02/17	01/03/17	02/03/17
Berdjansk (08:00)	4. W	4.W	4.W	2.E	6.E	7.E
Mariupol (07:00)	8.EW	8, W	0	1. NE	8, NE	8.NE
	03/03/17	04/03/17	05/03/17	06/03/17	07/03/17	08/03/17
Berdjansk (08:00)	4. N	3. NW	2, SE	4.E	6.E	8. E
Mariupol (07:00)	3. N	3.NW	0	5. E	6. E	11. NE

Since 02/19/2017, the daily average temperatures have become positive. According to the weather archive of the site meteo.ua and weather reports of the port of Mariupol the most repeated wind direction in Berdjansk is east (E – 8m/s, S – 5 m/s, SW – 4 m/s, NE – 3 m/s) and in Mariupol – northeast (NE – 7 m/s, C – 6, S – 5 m/s).

01.24.2017 – floating ice 9–10 points, cohesion 7–10 points;
01/25/2017 – floating ice 7–10 points, cohesion 10 points;
01/26/2017 – floating ice 7–10 points, cohesion 10 points;
01/27/2017 – floating ice 7–10 points; cohesion 9–10 points;
01/28/2017 – floating ice 8–10 points; cohesion 9–10 points;
01/29/2017 – floating ice 8–10 points of cohesion;
01/30/2017 – floating ice 10 points, cohesion 10 points;
01/31/2017 – floating ice 10 points, cohesion 10 points;
02/01/2017 – landfast ice 1 points floating ice 8 points cohesion 10 points;
02.02.2017 – fast ice 1 points floating ice 9 points cohesion 10 points;
02/03/2017 – landfast ice 1 points floating ice 9–10 points, cohesion 10 points;
02/04/2017 – landfast ice 7 points floating ice 3 points cohesion 10 points;
02/05/2017 – landfast ice 9 points floating ice 1 point;
02/06/2017 – landfast ice 9 points floating ice 1 point;
02/07/2017 – fast ice 1 point;
02/08/2017 – clean water;
02/10/2017 – floating ice 8–10 points, cohesion 8–10 points;
02/11/2017 – floating ice 10 points, cohesion 10 points;
02/12/2017 – floating ice 6 points, cohesion 10 points;
02/13/2017 – floating ice 2 points, cohesion 10 points;
02/14/2017 – floating ice 1 points, cohesion 10 points;
02/15/2017 – floating ice 3 points, cohesion 10 points;
02/16/2017 – clean water;
02/17/2017 – floating ice 5 points, cohesion 5 points;
02/182017 – floating ice 10 points, cohesion 10 points;
02/19/2017 – floating ice 6–10 points, cohesion 10 points;
02/20/2017 – floating ice 10 points, cohesion 10 points;
02/21/2017 – floating ice 10 points, cohesion 10 points
02/22/2017 – floating ice 4–6 points, cohesion 6–10 points;
02.24.2017 – floating ice 10 points, cohesion 10 points
02/25/2017 – floating ice 9–10 points, cohesion 10 points;
02/26/2017 – floating ice 5–10 points, cohesion 10 points;
02/27/2017 – floating ice 3–5 points, cohesion 10 points;
02/28/2017 – floating ice 5–7 points, cohesion 9–10 points;
03/01/2017 – clean water

The absence of buoy No. 1 of the Mariupol port PC was discovered on February 03, 2018 (the coordinates 46°53’8N37°27’4.0E). February 05, 2018 was found at coordinates 46°52’54.00 “C37°20’3.00” V. The displacement range is 9.4 km to the southwest.

According to the information of the ESIMO operational module "Ice conditions in the Azov Sea", the following ice characteristics were obtained in the area of the buoy displacement: 01/30/2018 – Nilas, ice ring. The total cohesion is 10 points, the prevalence of old ice. 02/06/2018 – Nilas, ice ring. The total cohesion is 10 points, the predominance of young ice (Fig. 4).



01/30/2018 *02/06/2018*

Fig. 4. The schemes of ice cover conditions
(In both diagrams, the dot indicates the regular position of buoy No. 1)

According to the weather report of the port of Mariupol, the following data were noted (average wind per day and the most repeated wind direction during the day) (Table 4):

Table 4

Average wind (m/s) per day and the most repeated wind direction (rumba) during the day

Port	02/02/18	03/02/18	04/02/18	05/02/18
Mariupol (07:00)	4. E	2. NE	7. SW	4. NW

According to the weather archive of the site meteo.ua and the data "Intervals of changes in the velocity of the current over the water area for various types and subtypes of wind fields" (*The project,* 1991) the following data were noted (average wind per day and the most repeated wind direction during the day) (Table 5).

The direction of the surface current coincides with the direction of the established wind. In the Taganrog Bay, due to the elongation of its configuration, this feature is less pronounced.

Table 5

The average data of the wind per day and the most repeated wind direction during the day (rumba)

	03/12/18	04/12/18	05/12/18	06/12/18	07/12/18
Average wind, m/s	4. E	8. E	8. E	3. N	4. NW
Marine velocity, sm/s		18–20	18–20		
	08/12/18	09/12/18	10/12/18	11/12/18	12/12/18
Average wind, m/s	2. W	5. ESE	6. E	7. E	7. SW
Marine velosity, sm/s		10–18	18	18–20	16–20

From January 12 to January 16, 2018, ice of the initial forms began to be observed in the Taganrog Bay. After stable frosty days, from January 30, 2018, warming began, and as a result, destruction and ice drift began. 02/04/2018 there was an increase in wind up to 9 m/s south – west direction. The ice campaign in 2020–2021 did not begin, although in places in the waters of the ports of Mariupol and Berdyansk there was a difficult ice. This winter marked the displacement of a large number of buoys from the Azov-Don Sea Canal (ADMK, Taganrog Bay, the Russian Federation) to Belosaray Bay.

According to the information of the NAVTEX warning system, the following ice characteristics were noted in the Mariupol region: 02/02/2018 – there was floating ice 7–9 points with cohesion 10 points; 02/03/2018 – there was fog. The absence of a landfill site buoy (the port area of Mariupol) was discovered on December 03, 2018 (with standard coordinates 46–58.0”N037–26.8”E). At December 12, 2018 a landfill site buoy was discovered at approximately 46°56’18”N37°23’03”E. The displacement range is 5.8 km to the southwest. In this period, there was no ice covering the sea, and the impact on the buoy was carried out only under the influence of a strong east wind and the current caused by it.

The purpose of considering the displacement of buoys under ice exposure is to determine the effect of the ice cover and its movement on the negative change in the navigation situation in order to improve the safety of navigation in the winter. The tendency of current growth of salinity in the Taganrog Bay due to a decrease of the Don River runoff, and the periods of ice formation are changing. It should be paid to studying the tendency of salt concentration not only in the coastal zones, but also in the central part of the Taganrog Bay and the Azov Sea in general as well. The ice regime of the Azov Sea is closely related with the sum of average daily air temperatures over the sea during the ice season. According to this criterion, winters are usually divided into three types: severe, moderate and mild. Over the past 30 years, there were only two severe winters in the Azov Sea in 2005–2006 and 2011–2012. During these winters, the Sea of Azov was completely covered by ice (Chepurna,

2018). And as mentioned earlier, the 2011–2012 ice campaign was extremely difficult in the navigation period.

For the buoys searching that were displaced by an ice field towards the open part of the f Azov Sea, one should take into account the rules of Nansen and Zubov. The speed of ice is less than the speed of the wind that excited it, about 50 times, i.e. $V_I = 0.02$ W, where V_I and W are the ice and wind speeds, respectively. In this case, ice does not move in the large water areas to the direction of the wind, but departs from it to 30° to the right in the Northern Hemisphere due to the action of the deflecting force of the Earth's rotation (Coriolis). The ice drifts along the isobar (the line of equal atmospheric pressure) so that the high pressure lies to the right along the ice movement, and the drift velocity is proportional to the horizontal gradient of atmospheric pressure.

More attention should be paid to the ice regime not only to the navigation component of shipping, but also to the impact to the coastal zone of the Ukrainian coast of the Sea of Azov. During the building processes and developing the coastal zone, it is necessary to take into account ice loads.

Ridges of hummocks are a natural component of ice cover. Hummocks are a heap of debris of thin ice above the upper and lower surfaces of smooth ice fields. Ridges of hummocks form from thin ice during the compressing by thicker ice. Very strong compression occurs during the ice movements with a high speed towards the boundary of landfast ice and coasts.

Moreover, the effect of dynamic exposure is greater and depends on the mass of ice and the ice cover area involved to the unidirectional movement. These situations are usual for Azov Sea. Some of synoptic situations form unidirectional ice drift perpendicular to the coastline and landfast ice boundary. A pressure of a large mass of ice to thin ice near the shore is squeezed out and form the accumulations of ice fragments powerful ridges of hummocks (Gavry`lyuk & Yuvchenko, 2019). Ice loads destroy the quays, tourism infrastructure, etc.

The moving the buoy depends on thickness of ice. Also because of shallow water in the Azov Sea, and especially in the Taganrog bay, and under the local impacts of the winds, the buoy shifts with an anchor behind ice cover.

CONCLUSIONS

The first (receiving) pair of buoys on the approach channel to the Harbor of Mariupol Port is most fall under the ice drift in the Taganrog Bay.

A powerful ice regime is not forming every winter.

During the period of ice cover formation in conjunction with strong winds, the influence of the ice regime to the operation of marine and coastal services is regularly observed.

In most cases, ice affecting to the shipping in the Mariupol port area, is formed in the mouth of the Don River and displaced by the Eastern and Northeastern winds.

In order to maintain the safety of navigation and reduce economic losses, in case of loss of a buoy, it is necessary to consider the possibility of removing buoys, which are most often displaced by ice, during the period of ice drift.

Long-term average observations indicate the beginning of ice formation in Mariupol on December 14, and in Berdjansk on December 20. The Taganrog Bay and the ice accumulation areas are clear of ice most recently of March 20–28. In a modern climatic change and increasing the frequency of mild winters, actual costs for the operation of ships like hydrographic, icebreakers, etc. in the ice fields are expected to be much lower than standard.

REFERENCES

Borovskaya, R. V. (2012). Otsenka ledovykh usloviy s ispolzovaniem dannykh ISZ. (*Assessment of ice conditions using satellite data)*. *Bulletin of the hydrometeorological center of the Black and Azov Seas*, № 1 (14), 196–212. [in Russian].

Chepurna, V. Yu. (2018). Minly`vist` l`odovogo rezhy`mu v Azovs`komu mori (*Ice regime variability in the Sea of Azov*): *materials of the ODECU Student Conference (May 7, Odessa. 2018)*, pp. 345–346. [in Ukrainian].

Don poteryal pervoe mesto po stoku v Azovskoe more. (*Don lost first place in runoff to the Sea of Azov).* Retrieved from http://azniirkh.ru/novosti/don-poteryal-pervoe-mesto-po-stoku-v-azovskoe-more/ (Accessed: 08.14.2019). [in Russian].

Gavry`lyuk, R. V., & Yuvchenko, N. M. (2019). L`odovi yavy`shha v Chornomu i Chzovs`komu moryax ta yix prognozuvannya v umovax klimaty`chny`x zmin. (*Ice phenomena in the Black and Azov Seas and their forecasting in the face of climate change). Ukrainian Hydrometeorological Station*, 24, 92–104. [in Ukrainian].

Kosenko, Yu. V., Baskakova, T. Ye. & Kartamysheva T.B. (2018). Rol stoka reki Don v formirovanii produktivnosti Taganrogskogo zaliva. (*The role of the Don River runoff in the formation of the productivity of the Taganrog Bay*). *Aquatic bioresources and habitat*, vol. 1, № 3–4, pp. 32–39. [in Russian].

Kulik P.V. Solenost vody v Azovskom more. (*Water salinity in the Sea of Azov*). (2019). Retrieved from http://gazeta-rv.zp.ua/mnenie-znatokov/1016-solenost-vody-v-azovskom-more.html (Accessed: 08.20.2019). [in Russian].

Ledovaya obstanovka v Azovskom more i Kerchenskom prolive [*Ice situation in the Sea of Azov and the Kerch Strait*] Retrieved from https://www.blackseanews.net/read/76280 (Accessed: 12.07.2019). [in Russian].

Ledovaya obstanovka v Azove – bez peremen k luchshemu. Na zapade – szhatie i torosy. Fotoreportazh. (*Ice situation in Azov – no change for the better. In the west – compression and hummocks. Photo report*). (2019). Retrieved from https://www.blackseanews.net/read/33760 (Accessed: 11.07.2019). [in Russian].

Lotsiya Azovskogo morya (№ 1243): posobie. (1985). (*Pilot of the Sea of Azov (No. 1243): allowance*). TsKF VMF, 160p. [in Russian].

Lysyy, A. A. (2015). Vliyanie faktorov ledyanogo pokrova na suda ledovogo klassa kak obekt upravleniya. *(Influence of ice cover factors on ice-class ships as a control object*). *Scientific Bulletin of the Kherson State Maritime Academy*, № 1 (12), 51–57. [in Russian].

Mariupol`sky`j mors`ky`j torgovel`ny`j port. *(Mariupol commercial sea port).* Retrieved from https://marport.net/uk/ (Accessed: 12.09.2019). [in Ukrainian].

Mironov, Ye. U. & Porubaev, V. S. (2012). Formirovanie gryad torosov v pribrezhnoy chasti Karskogo morya i ikh morfometricheskie kharakteristiki: Sovremennye problemy nauki i obrazovaniya. *(The formation of ridges of hummocks in the coastal part of the Kara Sea and their morphometric characteristics: Modern problems of science and education)*. No. 4. Retrieved from https://www.science-education.ru/ru/article/view?id=6707 (Accessed: 22.02.2020) [in Russian].

Porti Ukrainy. V Mariupolskom portu sozdan shtab ledovykh operatsiy (*Ports of Ukraine. Ice operations headquarters established in Mariupol port).* (2020). Retrieved from https://ports.com.ua/news/v-mariupolskom-portu-sozdan-shtab-ledovykh-operatsiy (Accessed: 10.02.2020). [in Russian].

Proekt «morya SSSR». Gidrometeorologiya i gidrokhimiya morey SSSR. Tom V. Azovskoe more. *(*T*he project "Seas of the USSR". Hydrometeorology and hydrochemistry of the seas of the USSR. Volume V. Sea of Azov).* (1991). M.: Gidrometeoizdat, 95p. [in Russian].

Savter, L. A. (2014). Sty`xijni gidrometeorologichni yavy`shha, shho sposterigaly`s` na akvatoriyi Chornogo ta Azovs`kogo moriv v 2014 r. *(Natural hydrometeorological phenomena observed in the Black and Azov Seas in 2014)*. *Bulletin of the Hydrometeorological Center of the Black and Azov Seas*, № 2 (17), 13–16. [in Ukrainian].

Stekhnovskiy, D. I. & Zubkov, A. Ye. (1977). Navigatsionnaya gidrometeorologiya *(Navigation hydrometeorology)*. M.: «Transport», 264p. [in Russian].

Nesterov O. Yu., Zagorodnya Yu. V., & Perepechayev S. M. (2021). Bezpeka moreplavstva z uraxuvannyam osobly`vostej l`odovoyi obstanovky`: Rozvy`tok transportu. *(Safety of seafaring due to the peculiarities of ice conditions: Development of transport)*, 1(8). Retrieved from https://tdjournal.org/index.php/journal/article/view/109/98 (дата звернення: 04.05.2021). [in Ukrainian].

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

Боровская Р. В. Оценка ледовых условий с использованием данных ИСЗ. *Вестник гидрометцентра Черного и Азовского морей*. Одесса, 2012. № 1 (14). С. 196–212.

Чепурна В. Ю. Мінливість льодового режиму в Азовському морі. Матеріали студентської конференції ОДЕКУ (Одеса, 7 травня 2018 г.). Одеса, 2018. С. 345–346.

Дон потерял первое место по стоку в Азовское море. URL: http://azniirkh.ru/novosti/don-poteryal-pervoe-mesto-po-stoku-v-azovskoe-more/ (дата звернення: 14.08.2019).

Гаврилюк Р. В. Льодові явища в Чорному і Азовському морях та їх прогнозування в умовах кліматичних змін. *Укр. гидрометеорологический ж*. Одесса, 2019. № 24. С. 92–104.

Косенко Ю. В., Баскакова Т. Е., Картамышева Т. Б. Роль стока реки Дон в формировании продуктивности Таганрогского залива. *Водные биоресурсы и среда обитания*. 2018. Том 1. № 3–4. С. 32–39.

Кулик П. В. Соленость воды в Азовском море. URL: http://gazeta-rv.zp.ua/mnenie-znatokov/1016-solenost-vody-v-azovskom-more.html (дата звернення: 20.08.2019).

Ледовая обстановка в Азовском море и Керченском проливе URL: https://www.blackseanews.net/read/76280 (дата звернення: 07.12.2019).

Ледовая обстановка в Азове – без перемен к лучшему. На западе – сжатие и торосы / Фоторепортаж. URL: https://www.blackseanews.net/read/33760 (дата обращения: 11.07.2019).

Лоция Азовского моря (№ 1243): пособие. *ЦКФ ВМФ*. 1985. С. 160.

Лысый А. А. Влияние факторов ледяного покрова на суда ледового класса как объект управления. *Науковий вісник Херсонської державної морської академії*. 2015. № 1 (12). С. 51–57.

Маріупольский морський торговельний порт. URL: https://marport.net/uk/ (дата звернення: 09.12.2019).

Миронов Е. У., Порубаев В. С. Формирование гряд торосов в прибрежной части Карского моря и их морфометрические характеристики: *Современные проблемы науки и образования*. 2012. № 4. URL: https://www.science-education.ru/ru/article/view?id=6707 (дата звернення: 22.02.2020).

Порти Украины. В Мариупольском порту создан штаб ледовых операций. URL: https://ports.com.ua/news/v-mariupolskom-portu-sozdan-shtab-ledovykh-operatsiy (дата звернення:19.02.2020).

Проект «моря СССР». Гидрометеорология и гидрохимия морей СССР. Том V. Азовское море. М.: *Гидрометеоиздат*, 1991. 95с.

Савтер Л. А. Стихійні гідрометеорологічні явища, що спостерігались на акваторії Чорного та Азовського морів в 2014 р. *Вестник гидрометцентра Черного и Азовского морей.* Одесса, 2014. № 2 (17). С. 13–16.

Стехновский Д. И., Зубков А. Е. Навигационная гидрометеорология. М.: «Транспорт», 1977. 264 с.

Нестеров О. Ю., Загородня Ю. В., Перепечаєв С. М. Безпека мореплавства з урахуванням особливостей льодової обстановки: *Розвиток транспорту.* 2021. № 1(8). URL: https://tdjournal.org/index.php/journal/article/view/109/98 (дата звернення: 04.05.2021).

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ВПЛИВ ЛЬОДОВОГО РЕЖИМУ НА ПРИБЕРЕЖНУ ЗОНУ АЗОВСЬКОГО МОРЯ

Азовське море відноситься до замерзаючих морів, що обумовлює необхідність прогнозу початку і закінчення формування льодових полів, складність обстановки льодових умов, які обмежують безпеку мореплавання. Розглянуто сучасні умови формування льодового режиму в Азовському морі. Від льодової обстановки, її тривалості та потужності льодового покриву залежить навігація в Азовському морі, зокрема українських портів Бердянськ і Маріуполь. Для проходження суден морськими підхідними каналами і рекомендованими курсами в зимовий період часу потрібне залучення криголамів. Знесення обмежуючих буїв льодовими полями і їх відновлення відбивається на економічних можливостях портів.

У роботі були використані дані прямих і дистанційних спостережень. Серед характеристик льодового режиму – дати появи льоду в районі морських портів України (Бердянськ і Маріуполь), характеристики льоду, закінчення льодоставу, розкриття і очищення від льоду акваторій портів і заток, інформація системи оповіщення NAVTEX, архівні матеріали сайту погоди meteo.ua. Розглянуто особливості фізико-хімічні властивості морських вод при формуванні льоду і генеральна циркуляція вод Азовського моря, що пов'язано з впливом прісного стоку річок Дону і Кубані. В період 2013–2020 рр. були проведені спостереження за зміщенням коштів навігаційного обладнання (буями) в зимові періоди з підхідних каналів порту Маріуполь і Бердянськ.

Мета статті – встановити характерні зимові періоди останнього десятиліття з урахуванням кліматичних змін для раціонального використання результатів про вплив на економічну діяльність морської інфраструктури.

Розглянуто характерні зимові періоди останнього десятиліття з урахуванням впливу кліматичних змін. Відзначено, що льодовий режим Азовського моря тісно пов'язаний з сумою середньодобових температур повітря над морем за сезон. За цим критерієм зими зазвичай діляться на три типи: суворі, помірні і м'які.

За останні 30 років на Азовському морі було тільки дві суворі зими в 2005–2006 і 2011–2012 роках. У ці зими Азовське море покривалося льодом повністю. Було розглянуто вплив льодового режиму на прибережну зону українського узбережжя Азовського моря, що дуже важливо для промислових і господарських потреб державного будівництва.

Встановлено, що не кожна зима супроводжується сильним льодовим режимом. При утворенні льодового покриву спільно з сильними вітрами регулярно спостерігається вплив льодового режиму на роботу морських і берегових служб. Для підтримки безпеки судноплавства та зменшення економічних втрат, необхідно розглянути можливість зняття буїв, які піддаються найбільш часто-

го зміщення під дією льодоходу, на період дрейфу льоду. Середні багаторічні спостереження свідчать про початок утворення льоду в Маріуполі 14 грудня а в Бердянську – 20 грудня. Найпізніше очищається від льоду Таганрозька затока і райони скупчення льодів – 20–28 березня. При сучасних кліматичних змінах (збільшення повторюваності м'яких зим, фактичні витрати на роботу судів (гідрографічних, криголамів і т.д.) в льодах очікуються на порядок менше нормативних показників.

Ключові слова: Азовське море, льодові умови, безпека мореплавання, кліматичні зміни.

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ВЛИЯНИЕ ЛЕДОВОГО РЕЖИМА НА ПРИБРЕЖНУЮ ЗОНУ АЗОВСКОГО МОРЯ

Рассмотрены современные условия формирования ледового режима в Азовском море. От ледовой обстановки, ее продолжительности и мощности ледового покрова зависит навигация в Азовском море, в частности украинских портов Бердянск и Мариуполь. Снос ограничивающих буев ледовыми полями и их восстановление отражается на экономических возможностях портов.
В работе были использованы данные прямых и дистанционных наблюдений. В период 2013–2020 гг. были произведены наблюдения за смещением средств навигационного оборудования (буями) в зимние периоды с подходных каналов порта Мариуполь и Бердянск.
Установлено, что не каждая зима сопровождается сильным ледовым режимом. Средние многолетние наблюдения свидетельствуют о начале образования льда в Мариуполе 14 декабря, а в Бердянске – 20 декабря. Позже всего очищается ото льда Таганрогский залив и районы скопления льдов – 20–28 марта.

Ключевые слова: Азовское море, ледовые условия, безопасность мореплавания, климатические изменения.