PAPER • OPEN ACCESS

Temporal variance of the ice navigation conditions within the Northern Sea Route

To cite this article: V Yu Tretyakov *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **937** 042095

Temporal variance of the ice navigation conditions within the Northern Sea Route

V Yu Tretyakov[1,2]*, A V Egovtseva[1], and V V Dmitriev[1]

[1] Institute of Earth Sciences, St. Petersburg State University, St. Petersburg, Russia
[2] Arctic and Antarctic Research Institute" (AARI), St. Petersburg, Russia

E-mail: v_yu_tretyakov@mail.ru

Abstract. Recognition of satellite images, composition of them and vectorization is used in AARI for ice charts production. There is discussed methodology and results of the ice charts processing by means of computer programs, which were elaborated by Dr. Tretyakov in Python. The paper demonstrates results of analysis of temporal variance of ice navigation circumstances within the buffer zone of the marine transport system from the Sabetta Port (the Yamal Peninsula, Russia) up to the Bering Strait. There are considered the variance for April and May from 1998 up to 2020. This intra-annual interval is the one with the heaviest ice circumstances for shipping. We used conditional length of various age and age and form gradations of the sea ice for the route as a whole, as an integral parameter for estimation of the navigation hardships of ice navigation. The conditional length of an ice age (thickness) diapason is result of multiplication of the diapason partial concentration at the length of the route leg with homogeneous ice characteristics. There were produced series of the conditional lengths for each ten-day periods during April and May. Then statistical homogeneity of the series was tested by various methods.

1. Introduction

Recent accident in the Suez Canal with container carrying ship “Ever Given” demonstrates vulnerability of the world economy to the events, which are usually named as “black swans”. This accident did not connect with the environment damage. The most dangerous “black swans” are ones which give a blow both economy and environment. Probably, the most dangerous of them are accident oil discharges. We should make mention such well-known events in the World Ocean as the accident with tanker «Exxon Valdez» in the Pacific Ocean in 1989 and the Deepwater Horizon oil spill in the Gulf of Mexico in 2010. The Russian Arctic has enormous resources of oil (7.3 milliards of metric tons), gas condensate (2.7 milliards of metric tons), and natural gas (about 55 trillions of cubic meters). About 41% of the resources are situated within the Russian Arctic shelf. These facts propose soon expecting of increase of the hydrocarbons transportation by shipping and pipelines including underwater ones. According to opinion of the Arctic Monitoring and Assessment Programme (AMAP, one of six Working Groups of International Organization the Arctic Council), the main danger for the Arctic Ocean environment is resistant organic matter and oil. The oil and liquefied gas can flow into the environment by exploitative (operational) and accident discharges. The operational discharges frequently take place, but have insignificant volumes. The accident discharges seldom occur, but can lead to disastrous consequences. Therefore, assessment of the Russian Arctic seas ecological wellbeing have to include assessment of ecological risk due to the accident discharges. The development of new oil and gas fields within the Russian Arctic shelf leads to increasing of shipping. The existence of ice cover considerably rises risk of sea accidents and, in turn, contamination of the environment. It is necessary to note that in Russia for a long time there prevailed the concept of absolute safety. It means that it is possible to create a safe system of any complexity. After the Chernobyl disaster appeared some review over assessment of the concept of safety for technical systems including transport systems. The key notion characterizing the degree of protection is safety. In general, safety is taken as a degree of protection from harmful inflicts of anthropogenic and natural factors. Often the term of “risk” is identified with probability of the disaster, natural catastrophe and so on. In the sphere of nature management, the term “risk” is understood as a probability of un-favorable consequences of natural and anthropogenic disasters. At such an approach, the term “risk” is a synonym of the term “probability”. The application of the term isn’t justified. Sometimes the term “risk” is used in a voluntary manner that is qualitative measure of the risk is used instead of quantitative one. In this case, the possibility of quantitative estimation of the risk is rejected at planning of nature management. The quantitative estimation of risk is necessary when we choose an optimum version of actions for example when we must choose strategy of the nature management.

In the near future, cargo transportation along the Northern Sea Route (NSR) is expected to increase due to the increasing rate of mining on the shelf, and the improvement of port infrastructure [1]. The analysis of ice conditions on the route of the NSR shows noticeable improvements for the navigation of ships, while it is worth noting that these changes do not indicate significant reductions in the risks of accidents [2]. The greatest danger for the environment is caused by accidents related to the spill of hydrocarbons. Environmental conditions, the remoteness of the marine environment, and increase of the accident risks negatively affect the ability to quickly eliminate spills [3]. The Polar Code identifies the following hazard conditions which increase the risk of accidents: severe ice conditions, icing of structures, low temperatures, long periods of polar night and polar day, rapidly changing and extreme weather conditions, possible lack of navigation security [4]. Conditions of low air and water temperatures, as well as the presence of ice, contribute to increase of the oil viscosity. It leads to decrease of the spills areas and speed of the oil slicks spreading on the sea surface, and to increase of the slicks thickness. In turn it affects the processes of evaporation of volatile components, emulsification and dispersion [5]. The oil spills undergo biodegradation, as in other climatic zones, but here the biodegradation processes have smallest intensity. It can be explained by short period of positive temperatures and effect of the low temperature at the oil-degrading bacteria activity [3]. The oil spills movement depends on the ice concentration. For example, if the total ice concentration is equal to 3 tenths or less, the oil spills and the sea ice move independently of each other. When the total ice concentration is equal to 3-8 tenths, the oil mainly moves with ice, and if the ice concentration more than 8 tenths, the oil completely moves with the ice cover. These special aspects are explained by several reasons. The oil can be trapped in the leads between the ice floes, absorbed by snow on the ice cover in the case of oil spillage on the ice cover surface, and trapped in depressions on the bottom surface of the ice [6]. Organisms may be exposed by the toxic effects of the oil situated in ice cracks for a long time. In this regard, it is necessary to take into account not only the resistance of the organisms to the oil contamination but also the duration of the influence [7]. One of the main features of Arctic ecosystems consists in significant seasonal dynamics with short period of intense spring-summer development with high productivity [8]. Seasonal dynamics makes Arctic species more vulnerable to hydrocarbon spills. During the period of ice melting, oil trapped in the ice cover can have toxic effect on the organisms. The period is one of the high biological productivity. The life cycle of many organisms is directly related to ice, so the toxic effects of the oil situated inside the ice and under the ice bottom surface can last for a long period [7]. At the same time, hydrocarbon spills can reduce the number of algae and meiofauna. It results in negative changes in the food chains [9]. Marine ecosystems have a complicated structure of interacting species. So hydrocarbon spills can affect the species with different force. The species located on the air-water interface are the most vulnerable to the oil contamination because the oil spills are situated on the water surface [10]. The oil prevents penetration of solar radiation into the water, while the radiation is necessary for photooxidation of organic substances. In addition, the oil slicks lead to disrupting of the heat and gas exchange between the ocean and the atmosphere [11]. Organisms of the Arctic ecosystems are more sensitive to human-induced impacts due to the slow biogeochemical cycles [7].

Computer simulation of the Russian Arctic seas ecological state and wellbeing demands simulation of the hydrocarbons accident discharges due to interactions between oil-carrying vessels and the ice cover. The accidents can be simulated by means of the Monte-Carlo approach, which demands statistical partitions of the ice cover parameters [12]. The partitions must be produced on the base of homogeneous baseline data. Therefore in the first instance we must examine homogeneity of the data. The conditional lengths can be used for the examination.

2. Materials and methods

The ice charts are automatically processed in ArcGIS by means of specially elaborated in Python computer programs. The first program reprojects the initial ice charts in reference system of the map document frame, and then intersects the reprojected ice charts with the buffer zone of the standard route from the Sabetta Port up to the Bering Strait. Width of the buffer zone is equal to 20 km. At the next step the program deletes needless fields in the attribute tables of the shapefiles, which are results of the intersection. Besides, the program deletes spatial duplicates in the results. The completive operation of the program is aggregating of spatial objects with the identical values of the all ice parameters in the shapefiles of ice situation within the buffer zone. The resulted spatial objects may be multipart ones. The second program calculates a number of values in the attribute tables of the shapefiles of the homogeneous ice zones within the buffer zone. These values are area of each homogeneous ice zone in square kilometers, proportions of the zones areas to total one of the buffer zone, and average length of the route within each homogeneous ice zone. The average length is result of the proportion multiplication at the total length of the route in nautical miles. The third programs calculates for the homogeneous ice zones within the buffer zone partial concentrations of old ice, old ice floes, thick first-year ice, thick first-year ice floes; conditional lengths of the route legs within old ice, old ice floes, thick first-year ice, and thick first-year ice floes. Then the program calculates aggregate values of the above-mentioned conditional lengths for the route as a whole. The program creates new polyline shapefiles, and set into the attribute tables the aggregate values. The tables have only one record that is the polyline shapefiles have only one spatial object. Part of the initial ice charts represent the ice conditions for ten-day intervals, but there are situations, when two initial ice charts correspond to one and the same ten-day interval. In this case we have to calculate average values of the conditional lengths for the interval. The fourth program does it. Finally, the fifth program merges the shapefiles with aggregate values of the conditional lengths in united shapefile. Of course, the program produces the united shapefiles separately for each ten-day interval. The records in the attribute tables have been sorted in ascending order of years. Thus the fields of the attribute tables contain ordered series of the conditional lengths.

Then the research consists in processing of the results by means of Mathcad. At first we plot graphs of cumulative curves. The sequence of the year numbers is set as the graph X-axis values. The sequence of the cumulative sums of a conditional length is set as the graph Y-axis values. Let us consider the cumulative curve of the conditional length of the route within old ice for a ten-day interval. The produced by Dr. Tretyakov Mathcad program puts the first point in the graph opposite the tick of the first year number on the X-axis, and opposite the value of the conditional length in the first year on the Y-axis. The second point is put with X-coordinate equal to the second year number, and Y-coordinate equal to sum of the conditional length in the first and second years. Thus, the points are put in the graph with ordinate values equal to sum of the parameter values from the first year up to this year, tick of which is situated in the graph opposite the point. The neighboring points are connected by straight lines. If the resulted cumulative or integral curve takes after a straight line, it means that there are no symptoms of heterogeneity of the initial sequence of values. Otherwise, existence of fractures and bends on the integral curve is the symptom of the sequence heterogeneity. In the first case the initial numerical series of the conditional length must be divided in twain. In the second case the series must be divided at place of the most conspicuous fracture or bend on the integral curve. The next stage of the research is testing of the initial series homogeneity by means of the non-parametric criteria of Wilcoxon-Mann–Whitney and Siegel–Tukey, which have been realized as designed computer programs of Mathcad.

3. Results

The conditional lengths as a percentage of the route are presented in the tables 1– 4. "4_1" means the first ten-day interval of April and so on. Year of 2002 is missed because there are no enough data for the research.

Table 1. Total conditional lengths of the route within the old ice as a percentage of the route "Sabetta Port – Bering Strait" length

Year	4_1	4_2	4_3	5_1	5_2	5_3
1998	14.2	15.4	18.2	14.9	23.1	23.4
1999	26.7	27.5	26.4	24.4	23.6	22.8
2000	6.9	6.3	6.1	6.3	5.9	6.4
2001	19.3	19.2	20.7	21.0	21.0	19.7
2003	0.0	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0	2.0
2005	2.7	2.9	2.9	2.7	2.6	2.5
2006	0.2	1.0	0.6	0.5	0.0	0.5
2007	0.2	0.2	0.0	0.0	0.2	0.1
2008	0.0	0.0	0.0	0.0	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0	0.0
2011	0.8	0.7	0.7	1.0	1.0	0.9
2012	0.0	0.0	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0	0.0	0.0
2014	6.4	5.2	4.6	4.6	4.0	3.4
2015	1.7	1.9	1.8	1.5	1.8	2.6
2016	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.2	0.4	0.0
2018	7.1	3.5	2.7	0.7	0.6	0.4
2019	3.3	3.6	4.0	4.1	4.6	4.8
2020	0.0	0.0	0.0	0.0	0.0	0.0

Usage of the integral curves method shows that all the curves of the total conditional lengths of the route within the thick first-year ice look like straight lines. The other integral curves have fractures. The fractures on the integral curves of the total conditional lengths of the route within the old ice and within big and vast floes of the old ice are situated in the graphs opposite the tick of year 2001. The curves of the total conditional lengths of the route within big and vast floes of the thick first-year ice have two fractures opposite the ticks of years 2003 and 2007. The first fractures are more pronounced ones. Therefore for usage of the Wilcoxon-Mann–Whitney criterion the series of the conditional lengths of the route within the old ice and within the big and vast floes of the old ice were divided in such manner. The first part of each numerical series includes the values of years 1998 – 2001. The second part of each numerical series includes the values of years 2003 – 2020. The series of the conditional lengths of the route within the thick first-year ice were divided in twain. In this case the first part of each numerical series includes the values of years 1998 – 2009, and the second part – the values of years 2010 – 2020. The first parts of the series of the conditional lengths of the route within the big and vast floes of the thick first-year ice include the values of years 1998 – 2003, and the second parts – the values of years 2004 – 2020. The Siegel–Tukey criterion can be used if both parts of a numerical series must have more 9 elements, or the smallest part mast have more 2 elements and the largest part must have more 20 elements.

IOP Conf. Series: Earth and Environmental Science **937** (2021) 042095 doi:10.1088/1755-1315/937/4/042095

Table 2. Total conditional lengths of the route within big and vast floes of the old ice as a percentage of the route "Sabetta Port – Bering Strait" length

Year	4_1	4_2	4_3	5_1	5_2	5_3
1998	4.7	5.1	5.8	5.0	7.7	7.8
1999	7.9	8.5	8.3	7.1	7.0	6.7
2000	1.8	1.7	1.7	1.9	2.0	2.1
2001	6.0	5.4	5.8	5.8	5.7	5.3
2003	0.0	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0	1.1
2005	0.5	0.3	0.3	0.3	0.2	0.3
2006	0.2	0.4	0.6	0.5	0.0	0.5
2007	0.2	0.2	0.0	0.0	0.2	0.1
2008	0.0	0.0	0.0	0.0	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0	0.0
2011	0.0	0.0	0.0	0.0	0.0	0.0
2012	0.0	0.0	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0	0.0	0.0
2014	1.2	1.0	1.0	0.8	0.6	0.4
2015	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.0	0.0	0.0
2018	2.0	0.7	0.5	0.1	0.0	0.0
2019	1.1	1.2	1.3	1.4	1.5	1.6
2020	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. Total conditional lengths of the route within the thick first-year ice as a percentage of the route "Sabetta Port – Bering Strait" length

Year	4_1	4_2	4_3	5_1	5_2	5_3
1998	64.0	60.0	61.1	58.9	55.0	54.6
1999	34.3	33.0	32.5	38.5	38.5	33.8
2000	35.8	39.8	39.1	39.4	36.9	36.2
2001	34.5	35.7	37.3	37.4	35.7	36.2
2003	60.4	63.2	65.4	57.7	60.2	59.3
2004	59.6	63.9	62.3	70.0	68.2	73.4
2005	43.5	41.0	60.3	60.9	58.9	56.7
2006	38.4	38.3	45.0	55.7	55.7	37.6
2007	53.1	56.0	56.9	56.6	51.5	48.2
2008	40.6	48.7	40.5	41.3	39.9	37.6
2009	47.0	49.0	54.9	54.5	52.3	51.6
2010	42.2	42.3	43.2	43.8	48.3	26.7
2011	41.1	46.5	50.9	48.4	47.8	45.8
2012	29.4	34.4	37.5	42.6	45.6	43.1
2013	47.3	55.8	53.7	52.1	59.6	55.1
2014	41.5	42.1	48.2	47.6	44.0	37.7
2015	34.5	37.3	50.4	49.8	49.2	45.8
2016	38.0	42.8	50.5	50.0	52.3	51.2
2017	29.4	36.2	38.3	38.3	38.5	39.0
2018	41.6	48.1	41.8	51.3	51.7	50.9
2019	33.6	38.0	42.2	47.6	47.0	47.1
2020	26.2	28.2	28.2	29.5	28.4	26.2

Therefore for the Siegel–Tukey criterion usage we divided the series of the conditional lengths in twain. According to results of the Siegel–Tukey criterion application the null hypothesis of the series homogeneity does not disprove itself with probability equal to 96% for all the series of the conditional lengths. It means that there are no differences between dispersions of the parts of the series.

Table 4. Total conditional lengths of the route within big and vast floes of the thick first-year ice as a percentage of the route "Sabetta Port – Bering Strait" length

Year	4_1	4_2	4_3	5_1	5_2	5_3
1998	17.5	15.4	15.1	18.1	13.7	11.3
1999	10.9	8.8	7.4	9.7	10.2	10.0
2000	9.8	13.4	14.8	13.8	13.9	12.5
2001	12.2	12.0	13.3	11.0	9.2	8.2
2003	13.8	14.6	17.6	15.5	16.7	15.6
2004	39.8	42.2	40.6	48.0	46.0	50.8
2005	43.1	40.6	42.2	43.2	41.1	38.6
2006	25.2	26.6	29.0	41.3	42.5	29.7
2007	38.1	41.1	38.5	41.1	36.7	28.8
2008	13.6	15.5	13.0	15.4	15.2	14.4
2009	18.2	18.7	21.0	20.6	19.0	19.2
2010	12.1	12.3	12.6	12.6	13.4	6.2
2011	11.3	14.3	15.2	13.8	13.7	13.3
2012	8.7	10.3	11.5	12.9	14.0	12.3
2013	13.4	13.8	14.0	13.4	16.0	14.7
2014	10.8	11.8	13.3	13.1	11.9	9.7
2015	9.6	10.1	11.8	11.2	11.4	10.9
2016	11.4	12.6	15.1	15.3	15.6	14.9
2017	8.2	10.2	11.6	11.5	11.5	11.0
2018	9.0	12.4	12.6	13.0	13.0	13.0
2019	9.4	10.4	11.4	11.4	10.5	10.7
2020	6.5	7.2	7.1	7.5	7.0	6.2

The results of the Wilcoxon-Mann–Whitney criterion application are presented in the table 5. Symbol "-" means that the criterion disproves the null hypothesis of the series homogeneity. Symbol "+" with a value in percentage terms means that the criterion proves the null hypothesis with the probability as a percentage.

Table 5. Results of the Wilcoxon-Mann–Whitney criterion application

Conditional length within	4_1	4_2	4_3	5_1	5_2	5_3	April and May
Old ice	-	-	-	-	-	-	
Floes of the old ice	-	-	-	-	-	-	
Thick first-year ice	-	+,14%	+,20%	+,12%	+,36%	+,48%	
Floes of the thick first-year ice	+,72%	+,72%	+,96%	+,60%	+,28%	+,32%	
Old and thick first-year ice							-
Floes of the old and thick first-year ice							+,14%

The results mean that there is significant variance of the old ice amount along the route for the period 1998-2020. Probably, there is no significant variance of amount of the big and vast floes of the thick first-year ice along the route for the period. The figures 1-2 demonstrate interannual variances of the average values of the conditional lengths of the route within the old ice and within big and vast floes of the old ice as a percentage of the route for the April-May interval.

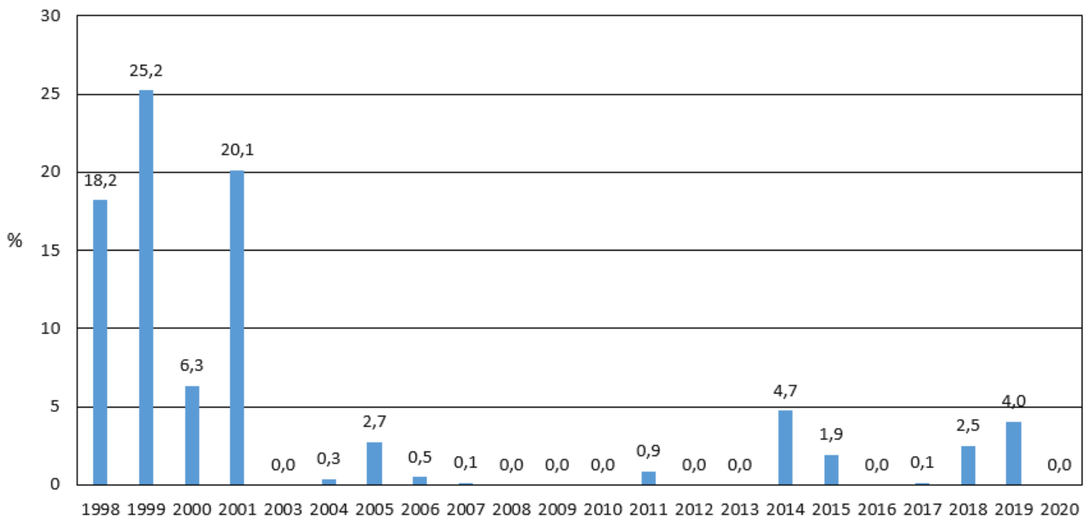

Figure 1. Interannual variance of the average value of the conditional length of the route within the old ice as a percentage of the route for the April-May interval

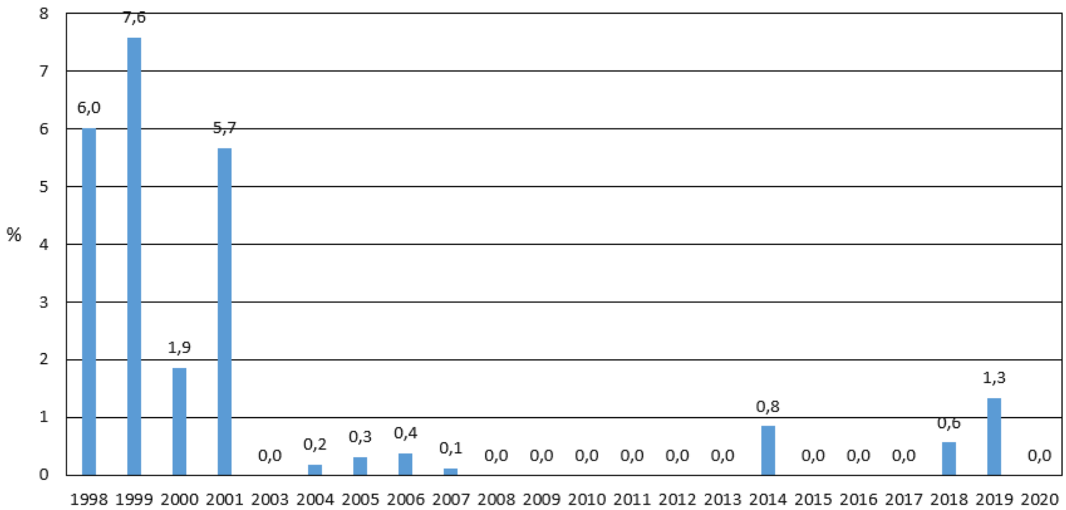

Figure 2. Interannual variance of the average value of the conditional length of the route within big and vast floes of the old ice as a percentage of the route for the April-May interval

4. Discussion and conclusions

It is evident significant decrease of the old ice amount along the route "the Sabetta Port – the Bering Strait". However there is no complete disappearance of the old ice from the route. The old ice can appear on the Northern Sea Route. Therefore shipping by the Route must be based on icebreaker assistance and scientific recommendations, which can be carried out by means of computer simulation.

Acknowledgements

The reported study was funded by RFBR projects numbers 19-05-00683a and 18-05-60291 Arctic, and Russian meteorological service project "Development of existing methods and technologies of long-term forecasting (months and seasonal ones) of ice and hydrological regimes of the Arctic Seas, the

Arctic rivers mouths in settings of the climatic changes and developing of the new methods and technologies", the project number is 5.1.2.

References

[1] Skripnuk D *et al* 2020 Analysis of the current state of the Northern Sea Route and the potential development of the icebreaker fleet *IOP Conf. Ser.: Earth Environ. Sci.* **539** 012129
[2] Tretyakov V *et al* 2019 Alterations of the heaviest ice conditions along Sabetta-Bering Strait route *IOP Conf. Ser.: Earth Environ. Sci.* **302** 012033
[3] Øksenvåg J et al , McFarlin K, Netzer R, Brakstad O, Hansen B, Størseth T (2018) Biodegradation of Spilled Fuel Oil in Norwegian Marine Environments: *A Literature Review (SINTEF Ocean AS Fate and Effects)*
[4] International Code for Ships Operating in Polar Waters (Polar Code) *RESOLUTION MSC*. **385 (94)** (adopted on 21 November 2014)
[5] Sørstrøm S *et al* 2010 *Joint industry program on oil spill contingency for Arctic and ice-covered waters : Summary report.* (**A14181** ed.) SINTEF.
[6] Venkatesh S *et al* 1990 Modelling the behaviour of oil spills in ice-infested waters *Atmosphere-Ocean* **28:3**, pp. 303-329, DOI:10.1080/07055900.1990.9649380
[7] Word J *et al* 2014 Environmental impacts of Arctic oil spills and Arctic spill response technologies: Literature review and recommendations (*Arctic Oil Spill Response Technology Joint Industry Programme (JIP)*.
[8] Azovsky A 2018 Analysis of long-term series of biological data: methodological problems and possible approaches *Journal of General Biology* **79** (**5**), pp. 329-341
[9] Kramer M 2011 The role of sympagic meiofauna in Arctic and Antarctic sea-ice food webs (*Doctoral dissertation, Christian-Albrechts-Universität*).
[10] Chang S *et al* M 2014 Consequences of oil spills: a review and framework for informing planning. *Ecology and Society* **19**(**2**) p. 26 http://dx.doi.org/10.5751/ES-06406-190226 [Accessed 7th April 2021]
[11] Problems of ensuring environmental safety in the development of navigation in the Bering Strait *Scientific and technical report. Vladivostok.* 2015. 40 P.
[12] Tretyakov V *et al* 2019 The results of computer simulation of the probability of accidents due to ship compressions by drifting ice along the Northern Sea Route *Russian Arctic* **5** pp. 4-11 DOI: 10.24411/2658-4255-2019-10051