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Statistical analysis of spatial variability in the position of ship routes in the Barents and Kara Seas

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ABSTRACT

The article proposes a concept for analyzing ship routes, based on calculating the probability of polygon intersection. Methods for calculating spatial density, quantile routes and interquantile areas were tested on AIS data on the year-round movement of Norilsk Nickel class vessels between the Barents and Kara Seas from 2009 to 2023.
Based on an analysis of more than a thousand routes from Murmansk and Arkhangelsk to the port of Dudinka, we obtained estimates of seasonal variability in the position of routes: ship traffic mainly goes through the Kara Gates; in spring, when ice cover most interferes with navigation, some routes go north of the Novaya Zemlya archipelago. The proportion of the northern route reaches its maximum in May (38%). For most of the year, both the median route and interquartile area (i.e. the area where 50% of all routes are located) of the route positions are almost identical to the shortest path between the ports under discussion. In the spring months, median routes deviate significantly from straight lines, and interquantile areas expand, covering possible for navigation areas associated with polynyas, fractures and leads in the ice cover.

KEYWORDS: Arctic navigation; statistical analysis of routes; Northern Sea Route; AIS data.

INTRODUCTION

The Northern Sea Route (NSR) is a major transportation passage linking together Europe and Asia, and connecting the northern territories of Russia. The largest deposits of oil, gas, and other raw materials have been found in the Arctic. The need to transport minerals and provide food and goods to localities in Siberia results in the observed increase in cargo turnover and ship traffic, creating the need to design and develop new transport hubs and shipping routes.
Severe environment conditions and especially sea ice cover make navigation along the NSR more difficult and force navigators to change the ship's trajectory and deviate from the standard routes. Thus, the actual route of ship movement in ice is an indicator of ice conditions in a given water area at the time of the ship movement. Statistical analysis of the spatial location of a set of routes can be a useful tool to assess the impact of environmental conditions on navigation, as well as obtain characteristics of the ship movement along the certain routes and determine their spatiotemporal variability.
Data from the Automatic Identification System (AIS) are source of information about the position of vessel routes. AIS equipment is installed on ships and provides automatic exchange of navigation information (coordinates, MMSI (Maritime Mobile Service Identity number), course of a ship, speed, etc.) between ships or coastal services for safety of navigation.
The introduction of AIS into shipping practice was primarily carried out to ensure the navigation safety. However, the accumulated information of AIS distributed by various aggregators (www.marinetraffic.com, www.shipsea.ru, maritime.scanex.ru, www.vesselfinder.com and many others) is successfully used to study the spatiotemporal pattern of vessel movements and to find dependencies between ship speed and environmental characteristics.
AIS data are widely used in various scientific tasks; these data are used to develop data clustering algorithms (Chen et al., 2022; Czarnowski, 2021; Fujino, Claramunt, 2023), find the relationship between ship speed and hydrometeorological conditions (Prithvi et al. 2021; Tremblett et al, 2021; Lucas, 2022), find the abnormal ship behavior (Rong et al, 2020). In the article (Tremblett et al, 2021), on the basis of the obtained information about the sea ice conditions and ice classes of the studied vessels, the POLARIS (Polar Operational Limit Assessment Risk Indexing System) methodology is applied to calculate Risk Index Outcome (RIO), which corresponds to each AIS record in the dataset.
Studies devoted to the analysis of ship traffic in the Arctic using AIS data are of particular interest. The papers (Pizzolato et al, 2014, 2016) assess shipping intensity and identify spatial relationships between shipping activity and sea ice concentration in the Canadian Arctic.
AIS data from regular year-round voyages of Norilsk Nickel class vessels between the port of Dudinka and the ports of Murmansk and Arkhangelsk can serve as a source of information on the ice navigation conditions between the Barents and Kara Seas. As a rule, navigation

between these seas is carried out through the strait between the Novaya Zemlya and Franz Josef Land archipelagos (the Makarov Strait), and the Kara Gates and Yugorsky Shar Strait (the straits to the north and south of the Vaygach Island). The Matochkin Shar Strait between the northern and southern islands of Novaya Zemlya is closed for navigation. The route from Murmansk to Dudinka through the Kara Gates is 52 nautical miles (nm) shorter than through the Makarov Strait, which is approximately 4% of the route length. The route from Arkhangelsk to Dudinka through the Kara Gates is shorter than the route north of Novaya Zemlya by 172 nm or 12% of the route length. Thus, all other things being equal, the route through the Kara Gates should be several hours faster (3-11 hours at a ship speed of 15.5 knots). However, sea ice and hydrometeorological situation can significantly change navigation conditions. It may happen that a longer route will be a faster and safer one.

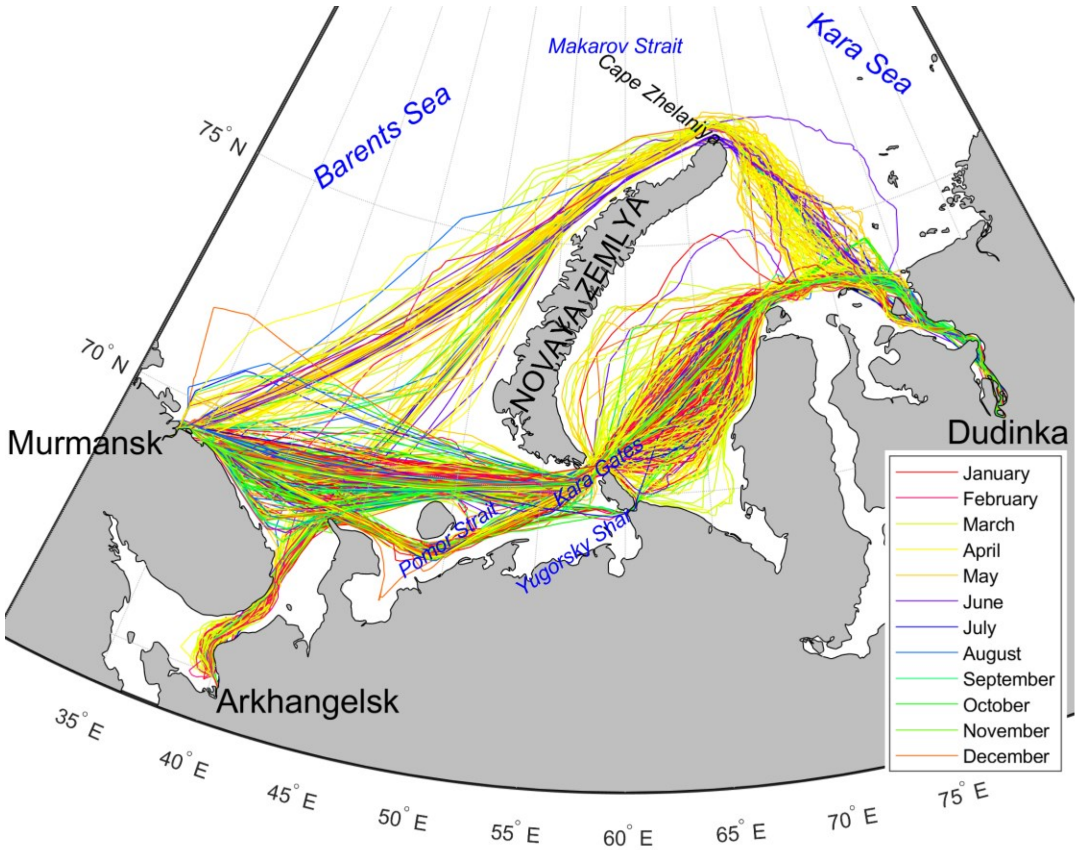

Fig.1. Traffic routes of the Norilsk Nickel class vessels between Murmansk/Arkhangelsk and Dudinka based on AIS data from 2009 to 2023.

AIS DATA OF NORILSK NICKEL CLASS VESSELS

The Norilsk Nickel Company mines non-ferrous metals in Northern Siberia. The port of Dudinka on the Yenisei River is used for the transportation of mined products. To ensure year-round transportation, the vessels of Arc7 ice class were built, namely “Norilsk Nickel” (2006), “Talnakh” (2008), “Monchegorsk” (2008), “Zapolyarny” (2008), “Nadezhda” (2009), “Yenisei” (2011). The last vessel is a tanker, the remaining ones are cargo container ships. A feature of the Norilsk Nickel class vessels is the presence of “Azipod” type propulsor, which consists of propeller and electric motor installed outside the ship hull by a link mechanism. In addition to the highest maneuverability characteristics, “Azipod” makes it possible to use the “double action” principle. When mooving in open water or in relatively light ice conditions, the ship moves bow forward with a maximum speed of up to 16.5 knots. In difficult ice conditions without icebreaker assistance, ship moves stern first, overcoming ice cover up to 1.6 meters thick at a speed of up to 3 knots. The AIS database at our disposal for the Norilsk Nickel class vessels contains information on the time and coordinates of the ship position from 2009 to the present.

The quality and time step of AIS data are not uniform over time: the first measurements were available only in the coastal zone, and sometimes the continuous record of ship movement coordinates is interrupted. Such records are not taken into account. In addition, only routes from Murmansk or Arkhangelsk to Dudinka, and routes in the opposite direction, are selected from the entire set of coordinates. Thus, we remove all routes with the intermediate call at the Gulf of Ob, as well as routes through the Norwegian Sea to Europe and transit routes along the Northern Sea Route to Asia. The AIS data contain outliers, which are first identified using special procedures based on a comparison of the maximum possible speed of the vessel and its movement and then removed. To sum up, we receive 1315 routes for the period 2009-2023, which are represented in Fig. 1. Of these, 664 routes were made towards the port of Dudinka from Murmansk (361) and Arkhangelsk (303), and 651 routes from the port of Dudinka to the ports of Murmansk (556) and Arkhangelsk (95). The following seasonal pattern has been revealed: from December to April each month accounts for 10% of the total number of routes, and from May to November each month accounts for 6-8% of routes. The fewest routes (6%) occur in June, which is due to the break in navigation during the spring ice drift on the Yenisei River. The remaining routes, in our opinion, can be used to analyze navigation conditions between the Barents and Kara seas.

METHODS FOR SPATIAL ANALYSIS OF ROUTES

Quantile routes and interquantile areas of route position

The concept we propose for analyzing ship routes is based on calculating the probability of the position of route elements relative to a selected baseline. To make it easier to interpret the position of the routes, it is reasonable to associate the baseline with some natural boundary (i.e., coastline, average position of multiyear sea ice edge, border of the exclusive economic zone, etc.). The coordinates of the points of each analyzed route are supplemented with the coordinates of the specified baseline. As a result of this transformation, a set of routes (linear vector objects) is transformed into a set of vector polygons P_n Thus, each polygon P_n consists of coordinates of ship movement obtained from AIS and coordinates of the given baseline.

The intersection probability for a set of polygons P_n can be calculated using the recurrent method for calculating polygon intersection probabilities (May et al, 2022). This method enables to analyze vector polygons without preliminary raster approximation, using standard operations from a set algebra: U - union, ∩ - intersection, \ - subtraction. For a set of polygons P_n, the polygons of intersection probabilities Q_p can be calculated by the following formulas:

$$Q^k_{\frac{n}{N}} = Q^{k-1}_{\frac{n}{N}} \cup R^k \qquad (1)$$
$$R^k = Q^{k-1}_{\frac{n}{N}} \cap R^{k-1}$$

where, $p=n/N$ is the intersection probability for polygons P_n; N – number of polygons, n – index number of a polygon P_n, n=1…N; k is index number of the step of the recurrent sequence, k=1...n, at step k=1 the intersection polygon R^k is equal to the added polygon P_n, and polygon of the probability of intersection is equal to the empty set Q_p=Ø. The justification of the method, as well as the algorithm for calculating the intersection probability for polygons and a link to the software implementation of the method are presented in (May et al, 2022).

The result of calculating the intersection probabilities for polygons based on AIS data by formulas (1) can be considered as a spatial analogue of the cumulative probability distribution function. The edges of the probability polygon $Q_{p=1}$ consist of route elements located closest to the given baseline (in our case, the coastline), and the edges of the probability polygon $Q_{p=1/N}$ consist of route elements as far as possible from the coastline. The probability isoline $Q_{p=0.5}$ divides equally the route elements: 50% of the elements are located closer to the baseline, and 50% of the track elements are located further from the shore. The edges of the polygon of probability 0.5 can be considered the median route, the edges of the polygons $Q_{p=0.25}$, $Q_{p=0.75}$ can be considered quartile routes, etc.

Quantile routes, that is, the edges of the corresponding probability polygon Q_p, consist of various elements of actual routes obtained from AIS data. In some cases, it is useful to select an analogue of a quantile route from a set of actual routes from AIS. This can be easily done using the condition of minimum area of the symmetric difference polygon as a selection criterion:

$$D_n = (Q_p \backslash P_n) \cup (P_n \backslash Q_p) \qquad (2)$$

From the entire set of ship routes, we select the one for which the area of the symmetric difference polygon D_n is minimal.

Such a representation in the form of a spatial analogue of the cumulative probability distribution function is not always convenient to analyze the position of ship routes. It is advisable to transform probability polygons Q_p into polygons of interquantile areas q_f:

$$q_f = Q_{p=\frac{1-f}{2}} \backslash Q_{p=1-\frac{1-f}{2}} \qquad (3)$$

If we subtract the probability polygon $Q_{p=1}$ from the probability polygon $Q_{p=0}$, then we obtain the boundaries of the area $q_{f=1}$, which contains f×100% of all ship routes. The polygon $q_{0.9} = Q_{0.05} \backslash Q_{0.95}$ covers 90% of the data, and the interquartile range polygon $q_{0.5}=Q_{0.25} \backslash Q_{0.75}$ covers 50% of all routes, etc. Inside all possible polygons q_f there lies the median line (median route).

Spatial density of routes

Raster approach and data representation in the form of thermal maps are mostly used in various GIS applications and online versions of AIS data aggregators for estimating spatial density. We propose an algorithm for calculating spatial density based on calculating the intersection probability for buffer zone polygons. For each route, a buffer polygon P can be calculated with vertices located at a given minimum distance L from any point on the ship route. Such a buffer polygon can be calculated using formula:

$$P = \cup_{s=1}^{S} (B_s \cup C_s), \qquad (4)$$

where s =1…S, S is the number of coordinates of the ship's position,

$$B_s = \begin{bmatrix} x_s, x_{s+1}, x_{s+1}, x_s \\ y_s, y_{s+1}, y_{s+1}, y_s \end{bmatrix} + L \begin{bmatrix} sin \\ cos \end{bmatrix} \left(\alpha_s - \frac{\pi}{2}, \alpha_s - \frac{\pi}{2}, \alpha_s + \frac{\pi}{2}, \alpha_s + \frac{\pi}{2} \right),$$

$$C_s = \begin{bmatrix} x_s \\ y_s \end{bmatrix} + L \begin{bmatrix} sin \\ cos \end{bmatrix} (\gamma),$$

γ=0…2π, [x_s, y_s] are the coordinates of the ship position, α_s is the course of the ship at point s, L is the width of the buffer zone.

Probability polygons Q_p of intersection of a set of buffer polygons P_n, calculated using formulas (1) provide polygons of the spatial density of ship routes:

$$F_{p \times \frac{N}{L}} = Q_p \qquad (5)$$

Spatial density has the dimension of the number of routes n per unit distance, for example, n/km.

To obtain a more detailed structure of the spatial density field of linear objects, several intersection probabilities for buffer zone polygons can be calculated sequentially with different values of L. Afterwards, the polygons of spatial density F, calculated for different L but with the same values of spatial density $p \times N/L$, can be combined:

$$F_{p \times \frac{N}{L}} = \cup_{i=p \times \frac{N}{L}} Q_{i,L} \qquad (6)$$

In some cases, such as when comparing different samples with different numbers of routes N, the spatial density can be normalized by the number of routes in the sample. In this case, the normalized spatial density has the dimension of probability per unit distance, for example, km^{-1}.

RESULTS AND DISCUSSION

Statistics of ships passing through the straits

Table 1 shows the distribution of routes for vessels of the Norilsk Nickel class depending on the year, season, and the strait used for passage. The routes are identified based on the analysis of AIS data after processing and removing the incomplete routes.

The table shows that the maximum number of voyages of the Norilsk

Nickel class vessels between the Kara and Barents Seas passes through the Kara Gates (91% of the total number of routes for all time). To the north of Cape Zhelaniya there are 8% of voyages and only 1% through the Yugorsky Shar Strait.

Table 1. Distribution of the number of routes between the ports of Murmansk/Arkhangelsk and the port of Dudinka by season, year and strait used for passage: the Makarov Strait / Kara Gates / Yugorsky Shar Strait.

year	Total number of routes	Winter	Spring	Summer	Autumn
2009	15	0/5/0	0/0/0	2/4/0	0/4/0
2010	11	0/3/0	0/7/0	1/0/0	0/0/0
2011	24	0/8/0	0/3/0	0/5/0	0/8/0
2012	56	0/17/3	1/13/0	0/10/0	0/10/2
2013	42	0/17/0	2/7/0	6/5/0	0/5/0
2014	53	0/21/0	0/10/0	1/5/0	0/15/1
2015	120	0/32/0	14/19/0	2/23/1	0/29/0
2016	126	0/41/0	0/38/0	0/21/0	0/26/0
2017	111	0/32/0	0/35/0	0/24/0	0/17/3
2018	108	0/28/0	20/15/0	6/22/0	0/17/0
2019	92	1/26/0	1/26/0	0/15/1	0/21/1
2020	141	2/41/0	0/36/0	0/32/0	0/30/0
2021	152	0/44/0	24/16/0	2/25/0	1/40/0
2022	124	0/35/0	19/14/0	1/27/0	0/25/2
2023	140	0/31/1	1/34/0	0/33/0	0/40/0
Total	1315	3/381/4	82/273/0	21/251/2	2/287/9

At the same time, there is a significant seasonal dependence in the distribution of ship routes by month: more than 95% of all routes pass through the Kara Gates from June to February, and only from March to June the proportion of routes passing north of Cape Zhelaniya exceeds 20% (maximum 38% is noted in May). Accordingly, the percent of passages of Norilsk Nickel class vessels through the Kara Gates in these months decreases proportionally. Data analysis makes it clear that less than 4% of the total number of voyages go through the Yugorsky Shar Strait. At the same time, ships do not use the Yugorsky Shar Strait at all from March to June.
Comparison of the routes connecting Dudinka with Murmansk and the routes connecting Dudinka with Arkhangelsk shows, that the monthly frequency of these routes passing through the Kara Gates is approximately the same. The only difference is observed from April to June: the voyages from Arkhangelsk through the Makarov Strait account for 46% in May and 22-25% in April and June, while voyages from Murmansk north of Novaya Zemlya account for 30-33% during the whole three months.
Table 1 shows that the number of voyages of Norilsk Nickel class vessels between the Barents and Kara Seas has been growing from 2009 (15 voyages) to 2015 (120 voyages per year). This growth is associated both with the commissioning of new vessels and with an increase in the quality of AIS data and changes in the organization of logistics. Since 2016, there have been an average of more than 100 voyages per year. It is useful to assess how the selection of preferable strait for passing between the seas varies over time.
Data analysis shows that during the period from 2009 to 2015 the probability of ships passing north of Novaya Zemlya was 52-53% in May and June, 14% in March, 19% in April, while during the period from 2016 to 2023 only 30-35% of ships used the northern route in April-May, 7% in March and 11% in June. Consequently, there is a pronounced tendency to use southern routes more often after 2015.

Seasonal variability of the median route and interquantile areas of route locations

There are two main routes between the Barents and Kara Seas, as it is shown in the previous section. These are the southern route through the Kara Gates and the Yugorsky Shar Strait, and the northern route through the Makarov Strait, north of Cape Zhelaniye of the Novaya Zemlya archipelago. It is reasonable to separate the calculation of quantile routes and interquantile areas for these two routes.
Figure 2 shows the median routes and interquantile areas of the routes of Norilsk Nickel class vessels between Murmansk/Arkhangelsk and Dudinka in different months.
The figure shows that from July to December the main route of vessel traffic goes through the Kara Gates, while the median route is a straight path from the strait to the Ob-Yenisei region. The interquartile area of route positions for this period is a narrow strip near the median route, i.e., 50% percent of all routes go near the median route. During these months, there are either no voyages north of Novaya Zemlya or there are not enough of them to estimate the median route and the interquantile areas of route positions.
Starting from January, the interquantile areas of the southern route expand towards the Yamal Peninsula, while the northern borders of these areas are still located near the median route. From February to May, the median route for passages through the Kara Gates deviates towards the Yamal Peninsula. In March and April, the interquartile area (i.e., the area where 50% of the elements of all routes are concentrated) expands both towards the Yamal Peninsula and towards the Novaya Zemlya. This spindle shape of the interquartile area is explained by the choice of optimal navigational routes passing along the polynyas, sea ice leads and zones of intense deformations of ice cover.
In May and June, the interquantile areas change again to an asymmetrical shape with the expansion of the western part of the areas towards the Yamal Peninsula.
For the northern route, the median route in May and June is a straight line between the northern tip of Novaya Zemlya and Yenisei Bay. In April, the median route runs to the west - it is directed towards the Gulf of Ob, and only in the southern part of the sea it turns towards Yenisei Bay. For the northern version of navigation, the interquartile zone is always symmetrical relative to the median route. The greatest width of the interquartile region is observed in May.

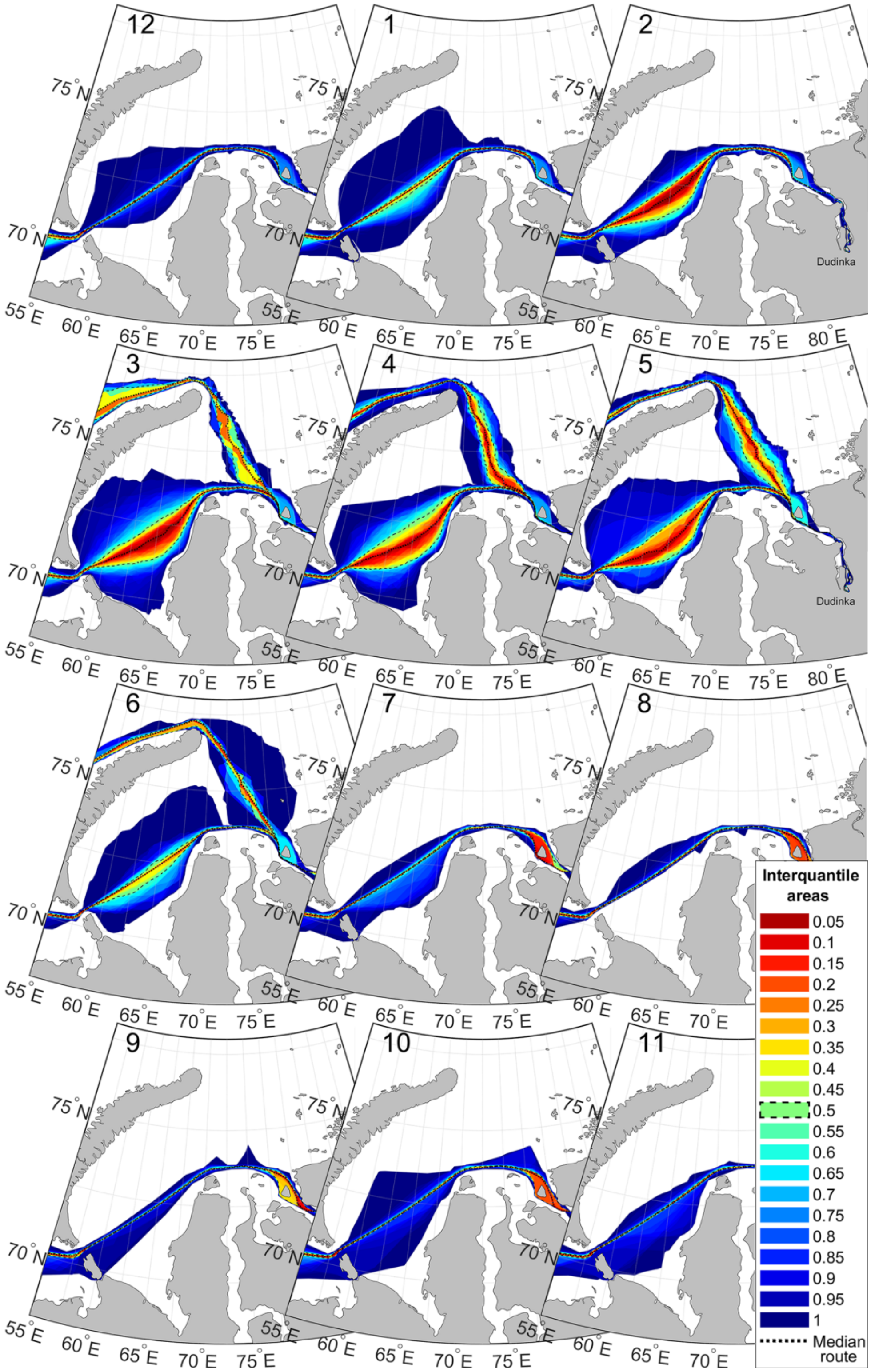

Fig.2. Median routes and interquantile areas of the routes of Norilsk Nickel class vessels between Murmansk/Arkhangelsk and Dudinka in different months in the period from 2009 to 2023 according to AIS data.

Analogue routes for median and side legs of the route

Ship routes in spring differ from the shortest straight-line route due to more difficult ice navigation conditions. For the southern navigation route in the area from the Kara Gates to the Ob-Yenisei region, three possible routes are traditionally distinguished: coastal (through polynyas near the Yamal Peninsula), central, and seaward route (Alekseeva et al, 2021). These routes can be identified by the form of interquantile areas in Figure 2 and by the spatial density distribution (Figure 4).

To find the actual paths of the Norilsk Nickel class vessels, which can be taken as the standard routes, we divide the area of possible route positions into three equal parts. We assume that the first third of the routes located closer to the coast of the Yamal Peninsula is represented by the quantile route with a probability of 0.166, the second third of the route is represented by the median route, and the last third of the routes is represented by the quantile route with a probability of 0.833.

The selection of analog routes is based on a criterion of the minimum area of the polygon of symmetric difference (formula (2)). For routes through the Kara Gates, the closest to the median route ($Q_{p=0.5}$) were ship paths on March 20, 2017 ("Monchegorsk"), April 29, 2023 ("Nadezhda") and May 9, 2017 ("Norilskiy Nikel"). The ship routes closest to the seaward route ($Q_{p=0.833}$) were on March 23, 2017 ("Talnakh"), April 11, 2019 ("Zapolyarny"), May 21, 2016 ("Zapolyarny"). Analogues for the quantile route $Q_{p=0.166}$ (coastal route) for the corresponding month were routes on March 18, 2014 ("Monchegorsk"), April 24, 2017 ("Monchegorsk"), May 13, 2023 ("Monchegorsk").

For the northern route through Cape Zhelaniya, the route legs are usually not identified (Alekseeva et al, 2021). In this article, we list analogues of the quantile routes $Q_{p=0.166}$, $Q_{p=0.5}$ and $Q_{p=0.833}$ for two months. In April and May, the median route corresponds to the routes on April 19, 2021 ("Enisey") and May 16, 2022 ("Zapolyarny"), respectively. The western leg of the route ($Q_{p=0.833}$) corresponds to the routes on April 3, 2021 ("Zapolyarny") and May 18, 2015 ("Norilskiy Nikel"). The eastern leg of the route ($Q_{p=0.166}$) corresponds to the routes on April 25, 2022 ("Nadezhda") and May 6, 2021 ("Talnakh"). The listed routes are presented in Figure 3.

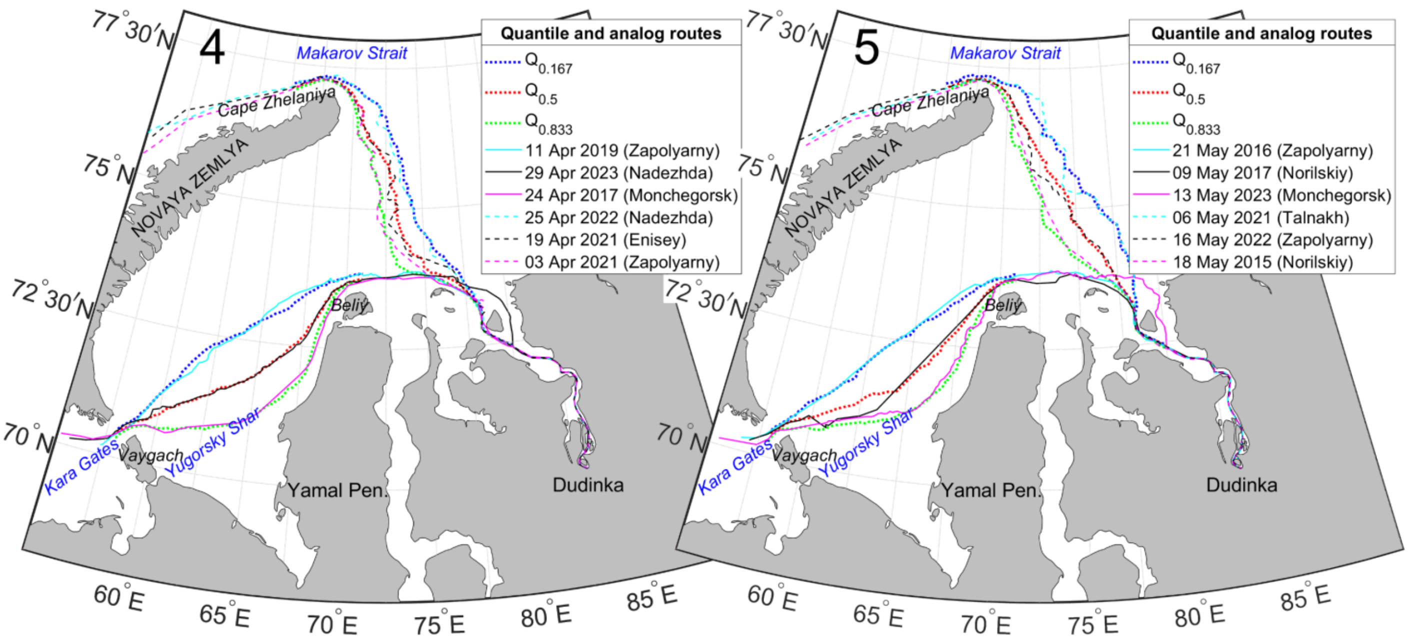

Fig.3. The routes of the Norilsk Nickel class vessels are closest to the quantile routes $Q_{p=0166}$, $Q_{p=0.5}$ and $Q_{p=0.833}$.

Spatial density of routes

Figure 4 presents the spatial density of the routes in different months. The figure shows that spatial density in the Barents Sea depends on the destination or departure point of the vessels (Arkhangelsk or Murmansk). Furthermore, the choice of the route depends on meteorological conditions in this area. It can be proved by the changes of course or the choice of unusual routes for sailing through the Pomor Strait south of Kolguev island. Such features in the distribution of spatial density are associated with the presence of storms, strong waves, etc. in the Barents Sea. Whatever the variations in the position of the routes in the Barents Sea, they all come to zero in the Kara Gates or north of Cape Zhelaniye of the Novaya Zemlya archipelago. The path from these turning points to the port of Dudinka no longer depends on the variation of routes in the Barents Sea.

Figure 4 confirms the above-described patterns of distribution of voyages through the straits by month. The path through the Kara Gates is the most usual route for the Norilsk Nickel class vessels. The spatial density there exceeds 10 routes per 1 km in all seasons. The routes north of Novaya Zemlya (Makarov Strait) become most active from March to June. At this time, the spatial density north of Cape Zhelaniya exceeds the value of 3 routes per 1 km.

The variability of spatial density of the shipping routes in the Kara Sea is of our main interest. From June to December, the highest spatial density (more than 10 routes per 1 km) remains in the straight line from Vaygach Island to Beliy Island. Starting from January, the rate of spatial density on the straight-line route leg drops to 3-4 routes per 1 km. Since February, a pronounced arc-shaped concentration of spatial density values has appeared near the Yamal Peninsula. The spatial density on the central and coastal straight-line legs of the route is approximately the same in March (2-3 routes per 1 km); in April the structure of spatial density on the central route is "blurred" into 3-4 filaments with density values up to 1-2 routes per 1 km. At the same time, the spatial position of the coastal route along the polynya remains the same with spatial density of 2-3 routes per 1 km. The central route becomes focused again in May; the values of spatial density on the central and coastal straight legs become comparable again. The seaward route in the southwestern part of the Kara Sea is spatially unstable.

The density of routes near Cape Zhelaniya increases significantly in spring. The pattern of spatial density in the area from Cape Zhelaniya to Yenisei Bay is a set of sometimes intersecting filaments with values of 1 route per 1 km. Only in June, the spatial density is focused into one strip on this section of the route.

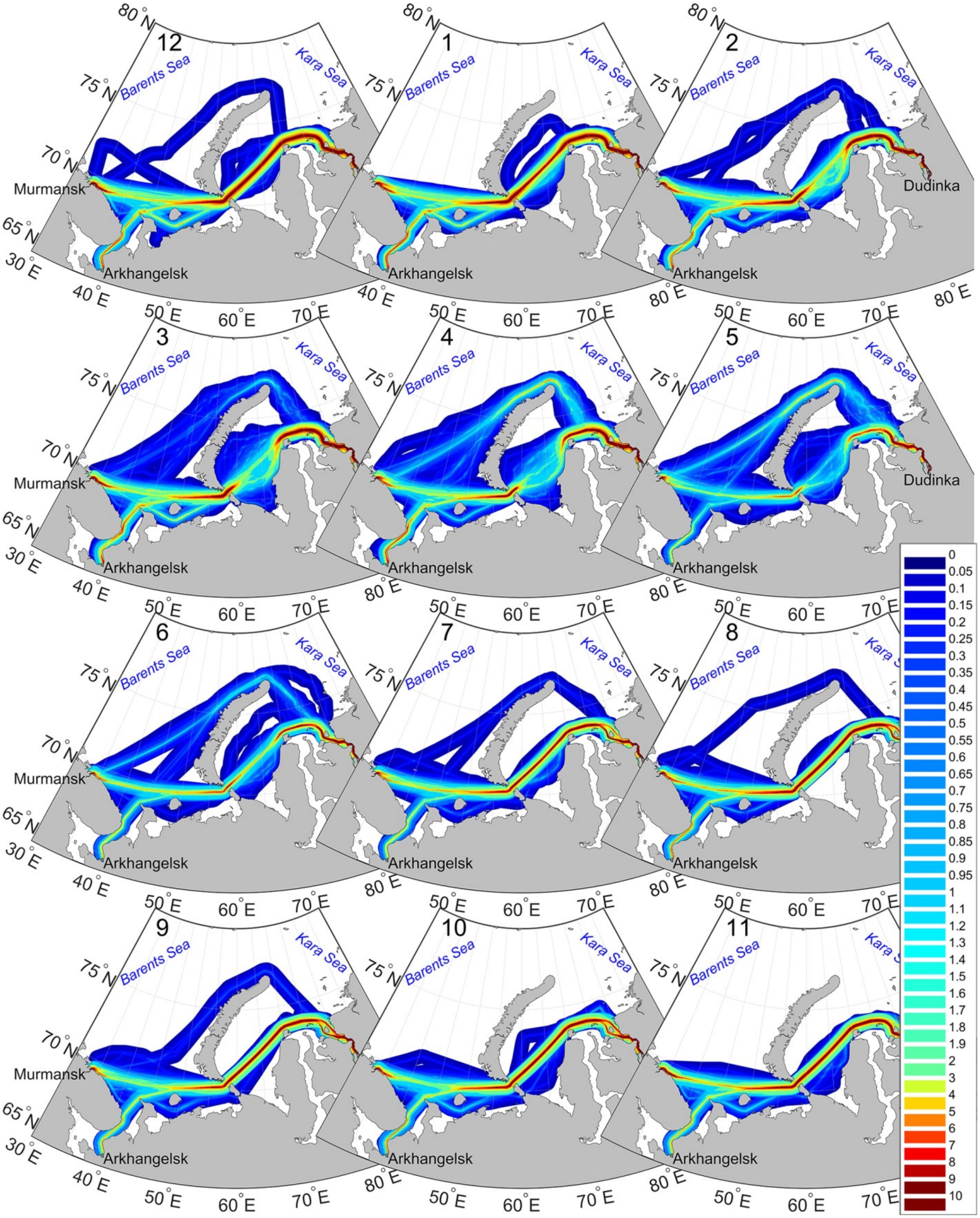

Fig.4. Spatial density of routes for vessels of the Norilsk Nickel class, number of routes per 1 km.

CONCLUSIONS

It is known that the speed of a vessel in ice is an integral indicator of ice navigation conditions. Features of the vessel's trajectory in ice depend on the spatial distribution of the ice cover characteristics. Consequently, statistical analysis of multiple ship routes in ice will reveal the spatio-temporal variability of ice characteristics that affect navigation.

To solve this problem, we have developed methods for assessing the statistical characteristics of the spatial position of ship routes: calculating quantiles of route positions, interquantile areas, finding analogue routes and calculating spatial density. All of these methods are based on calculating the probabilities of intersection of polygons and do not require specifying the grid area.

For analysis, we select AIS data from the Norilsk Nickel class vessels, which make regular year-round voyages between the Barents and Kara seas. Our results show that the main traffic between the seas passes through the Kara Gates. In the spring months, when the ice thickness reaches its maximum, some routes (up to 38% of the total number of routes in one month) pass north of the Novaya Zemlya archipelago. In this case, the spatial density of routes at Cape Zhelaniya exceeds 3 routes per kilometer. For example, the spatial density in the Kara Gates in all months exceeds 10 routes per kilometer.

Analysis of the spatial position of routes in the Kara Sea shows that the median route between the Kara Gates and the Ob-Yenisei region is basically a straight line, but the median route is curved towards the Yamal Peninsula in spring. The interquartile area, covering 50% of the routes, expands towards the Yamal Peninsula and towards the Novaya Zemlya archipelago in spring. Such a spread of routes from March to June is caused by the formation and closure of polynyas and formation of areas of intense dynamic of sea ice cover.

For routes between the northern tip of Novaya Zemlya and Yenisei Bay, the median route is a straight line in May and June, and in April the median route moves west. The interquartile area is symmetrical about the median route. The spread of route positions in this part of the sea is determined by the location and orientation of leads in the ice cover.

To standardize the position of the routes, quantile routes are identified for probabilities of 0.166, 0.5 (median route), and 0.833. For each of them, an analogue is selected from the actual voyages based on the AIS data.

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