Study of ship speed regimes in the Arctic sea ice conditions

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Abstract. An increase of commercial navigation in the Arctic along the Northern Sea routes will involve the use of large-capacity vessels of high ice-class during the non-escorted transit. To ensure the safety of Arctic navigation, it is necessary to have unbiased data on the influence of ice thickness on vessels’ speed and maneuverability. The paper suggests using a geoinformation system which includes data on speed and routes of the vessels of various capacities, as well as data of remote sensing of the earth about ice conditions. Two parts of traditional routes in the western part of the Russian Arctic were considered: the sea crossing from the Barents Sea to the Kara Sea through the Kara Strait and the transition from the Barents Sea to the Kara Sea through the Cape of Desire. A joint study of this data (layers) on the example of winter navigation of 2018 provides detailed information on the trends of speed reduction of ships under the conditions of fully consolidated ice. Based on the results of the study, the results are presented for four groups of vessels with different gross tonnage, capacity, ice pass and draft. To compare the results, the measured velocities were normalized to relative ones, which made it possible to identify common dependencies and trends. The availability of archival data on measurements of ice thickness in the geographic area under study and the predictive models for increasing ice thickness during the winter time mad it possible to develop adequate methods aimed at estimating the change in the properties of ice by varying the speed of vessels of various classes on the routes in the water area of the Northern Sea Route. Statistical processing of vessel speed in the ice fields made it possible to identify the sameness of the speed-reduction trends for the main groups of vessels and the distinctive features associated with the vessel’s power and the use of icebreaker support.

1. Introduction

A significant increase in cargo turnover in the water area of the Northern Sea Route (NSR) in the coming years will require the organization of vessel traffic as part of maritime traffic flows at a high commercial speed. The main factor affecting the reduction of the vessel’s speed is the ice situation. Experimental methods [1], as well as models [2] and computer modeling [3] are used to evaluate the influence of ice on the speed and maneuverability of vessels. In this case, the possibilities of field trials in some cases have significant limitations associated with inability to actively influence on ice conditions during the research at the selected site at a given time [4, 5]. The latter significantly affects the representativeness of the experimental data. To overcome this shortcoming, it is proposed to expand the database of experimental data through regular operational navigation and hydrometeorological information.
Taking into account the fact that it is almost impossible to perform direct continuous measurements of the ice properties along the vessel’s way, it is proposed to change the traditional approach of investigating the influence of ice on the speed regimes of ships.

To ensure the safety of ice navigation, it was proposed to share the data obtained from the automated information system (AIS) of vessel traffic and the forecast of the ice situation in paper [6]. The method has features related to synchronization of incoming information. Data on the ice situation, as a rule, have a delay of 3-5 days. Such a delay results in the discrepancy between the results of measuring the speed of vessels to the ice parameters on the route.

With linear motion of the same ship’s type in ice at a fixed capacity of the ship power plant, the change in the speed of vessels along the route is mainly affected by the change in ice resistance, which depends on ice thickness, its strength properties and other characteristics. Thus, by studying the nature of the change in speed along the route, one can obtain some integral assessment of the nature of the change in ice resistance and changes in the basic properties of ice, for example, ice thickness or its consolidation.

In papers [7, 8], it was proposed to use geographic information system (GIS) to analyze the ship’s high-speed regimes in the water area of the NSR which ensures detailed visualization of the sea traffic flows and identification of straight parts of routes of the same type of vessels the movement of which is carried out at the same power.

The aim of this study is to investigate the speed change of large-capacity vessels on the routes in the water area of the NSR with the increasing ice thickness.

2. Methods and Materials

To solve the task, the geographic information system (GIS) of the NSR was used which contains information on the location of all ships operating in the water area of the Arctic seas, as well as the parameters of their movement.

Out of the vessels that have received the permission to work in the waters of the Northern Sea Route, 15 vessels operating in the western sector of the Arctic (the Kara Sea) on the yearly basis were selected. All vessels were divided into 3 groups according to the table 1.

| Characteristics | YamalMax | 42K | Norilsk Nikel |
|-----------------|----------|-----|---------------|
| Function        | LNG tanker | Oil tanker | shuttle | General cargo |
| Ice Class       | Arc7     | Arc7 | Arc7 |
| Capacity of ship power plant, MW | 45 | 32 | 18 |
| Ice capability, m | 2.1 | 1.8 | 1.5 |
| Draft, m        | 12       | 9.5  | 10  |
| Capacity, thousand tons | 128.8 | 44.3 | 17 |

Observations were attributed to the beginning of winter navigation (the first decade of February 2018) and to the end of winter navigation (the first decade of June 2018). Ice conditions during the observation period were characterized as the light and medium ones, which allowed vessels with the Ice Class Arc 7 to make independent voyages in the western sector of the Arctic. Two parts were considered: the sea crossing from the Barents Sea to the Kara Sea through the Kara Strait and the transition from the Barents Sea to the Kara Sea through the Cape of Desire.

The choice of these parts was due to the fact that during the period under review the Barents Sea was completely freed from ice, which made it possible to determine the speed of vessel on clean water, whereas the water area of the Kara Sea was almost completely covered with consolidated ice. The processing included data on the movement of similar groups of vessels within the ice fields. As auxiliary information, operational ice data was used, which was publicly available on the websites of
the Administration of the Northern Sea Route [9], the Arctic and Antarctic Research Institute (AARI) [10], the National Snow and Ice Data Center (NSIDC) [11], as well as those contained in the monograph [12]. The investigative information of the NSIDC is in open access with the delay of three days. The AARI forecasts on ice conditions are provided in advance for the period of 3 to 30 days. According to archival data [9-12], in the beginning of the winter navigation the water area of the Kara Sea was almost completely covered with one-year ice the thickness of which equaled to 0.4-0.7 m with the ice concentration of 7 points. At the end of the winter navigation period the water area was covered with consolidated ice of 7-10 points. Its thickness amounted to 1.5 m with hummocks. The perennial ice was absent.

A number of assumptions and simplifications concerning the structure and physical properties of ice and ice fields were used during the development of the models. The assumptions made affect the accuracy of calculations; however, they do not make any significant influence on the correctness of the interactions described by the models.

3. Results

The results of measuring the speed of large vessels on the routes in the water area of the NSR are presented in Fig. 1-3.

The vertical axis of the graphs denotes the normalized speed of vessel. The maximum open water speed was used as a rate of setting for each type of vessel.

Fig. 1 shows the data on the speed of a group of ships of YamalMax. The solid line in the graph shows the trend line of the change in speed which corresponds to a decrease in the speed of linear dependence. For YamalMax ships the maximum speed on clean water is 20 knots and the breakability of ice is 2.1 meters. The speed rate has decreased monthly by 7.2% during the mentioned period.

![Figure 1. Change in the speed of LNG tankers](image)

Fig. 2 shows speed data of a group of ships of the type 42K. During the observation period, the relative velocity has decreased by 6.5% per month. For ships of the type 42K the maximum speed on clean water is 14.5 knots and the breakability of ice is 1.8 meters.
Fig. 3 shows speed data of a group of ships of Norilsk Nickel. During the observation period, the relative velocity has decreased by 9.5% per month. For vessels of Norilsk Nickel, the maximum speed on clean water is 15 knots and the breakability of ice is 1.5 meters.

4. Discussion

The above results show that during the winter navigation there is a steady decrease in the relative velocity of large-capacity vessels in the ice ranging from 6.3 to 9.5%.

According to the ice observations for the denoted period, the ice thickness varied from 0.5 to 1.5 meters along the NSR routes. The graphs of speed changes for different the types of ships retain the general trend; however, each of them has its own peculiarities of changing the speed regime in the ice fields. High power vessels and vessels under the icebreaker’s wiring perceive maximum resistance only at the end of the winter navigation when the ice thickness is over 1 m.

The results obtained are in agreement with the data provided in papers [13-15]. It should be noted that at speed of up to 4-6 knots, when the ships lose their maneuvering characteristics, observations related to the study of the effect of ice on the ship speed have significant limitations.
5. Conclusion
The obtained results are consistent with the theoretical models and simulation results. The prevailing influence of changes in ice conditions on the decrease in the speed of large-capacity vessels was confirmed.

The results obtained cannot be considered final, since they are based on a limited amount of statistical data of 2018. In the future, it is proposed to expand the investigation period and to clarify the structure and the type of functional dependence which makes it possible to assess the changes in the ice conditions along the ship’s route by measuring the change in vessel speed. The obtained estimates can be used to refine the ice maps and adjust the speed of other types of vessels.

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