Navigational hazard by sea ice along the North East Passage

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In parallel with rapid retreat of Arctic seas ice, the Arctic Ocean has been attracting maritime sector to utilize the Arctic Sea route between the Atlantic and the Pacific Ocean (Fig.-1). Since 2010, some trial voyages were carried out. And then commercial use of the North East Passage along the Russian Arctic coast started to increase for transporting natural resources such as iron ore and gas condensate. Furthermore, Russia started liquefied natural gas (LNG) transport and crude oil transport from the Yamal Peninsula and the Kara Sea coast. Today, annual total transported cargo volume reached 30million tons, which accounts for fivefold of 1980's maximum record, owing to the LNG and crude oil transport. Here, the most notable point is year-round transportation of LNG by 15 of icebreaking LNG carriers. In spite of the sanction imposed against Russia in response to the war of aggression against Ukraine, year-round natural resource (mainly LNG and crude oil) transport via the North East Passage still remains mainly by Russian shipping sectors.

Thus far, there was no significant maritime accident which causes environmental damage. However, there were some incidents that cargo ships became unable to navigate (beset) due to harsh sea ice condition along the North East Passage. This paper investigates these incidents by using satellite AIS record and sea ice condition by TPAZ4 ocean-sea ice data assimilation system. In early November 2021, about 20 ships were beset in the East Siberian Sea and the Chukchi Sea due to harsh sea ice (Voytenko, 2021). All of them were rescued by Russian nuclear icebreaker, but some of them were forced to wait rescue for more than a week in the ice-covered sea. In this paper, three typical incidents of cargo ships were investigated (Table-1). Fig.-2 shows ship track of three cargo ships. The ship-2 sailed independently about one week ahead of rest of the two ships along the almost same route. Fig.-3 shows the ice thickness and ship speed. Here, Part-1 and Part-3 shows icebreaker supported operation before and after the beset incident. And Part-2 shows independent navigation (Fig.-4). In the case of icebreaker supported navigation plotted as part-1 and part-3, ship speed reached nearly 10 knots even ice thickness exceeds 1.0m. On the other hand, ships were unable to operate when ice thickness reached 0.5m~1.0m in the case of independent navigation (Otsuka, 2023).

From this information, sea ice thickness not always exceeds navigational limit of cargo ships, which is about 70cm, when beset incident occurred. One of possibility of this might be sea ice convergence/divergence behavior. To assume sea ice convergence, Kimura (2004) introduced sea ice convergence factor by equation (1). Here, authors introduced sea ice thickness and ice concentration to this as equation (2). This $\dot{\nabla}vol_{ij}$ could be an ice volune change ratio when it beomes negative means ice volume increases and ice convergence increases. Fig.-5 shows distribution of $\dot{\nabla}vol_{ij}$ when best incident occurred on November 12th and 15th. The water area in the East Siberian Sea where the incident occurred showed slightly negative $\dot{\nabla}vol_{ij}$. Authors are currently examining another incident cases to invetigate the relationship between this ice convergence factor and navigable hazard for cargo ships.

$$\dot{\nabla}_{i,j} = \frac{u_{i+\frac{1}{2},j} - u_{i-\frac{1}{2},j}}{dist} + \frac{v_{i,j+\frac{1}{2}} - v_{i,j-\frac{1}{2}}}{dist} \qquad (1)$$

$$\dot{\nabla}vol_{ij} = B \cdot dist \cdot \left(\frac{vol_{x\,i+\frac{1}{2},j} - vol_{x\,i-\frac{1}{2},j}}{dist} + \frac{vol_{y\,i,j+\frac{1}{2}} - vol_{y\,i,j-\frac{1}{2}}}{dist} \right) \qquad (2)$$

$$vol\_x_{i,j} = concentration_{i,j} \times thickness_{i,j} \times u_{i,j}$$

$$vol\_y_{i,j} = concentration_{i,j}$$

Here,
u_{ij}, v_{ij} :drift vector of East-West, South-North direction(m/s)
B :unit width (1.0m)
dist :grid size (12.5km)
concentration : sea ice concentration
thickness :sea ice thickness(m)

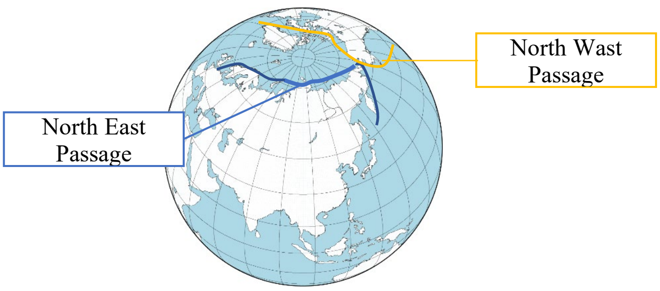

Figure-1 Arctic Sea Routes

Table 1.　List of ships that disabled by sea ice

	Ship type	DWT	Ice class	Incident water area
ship1	Bulk Carrier	74,300	FS 1C/Ice 2	East Siberian Sea
ship2	Bulk Carrier	95,758	1A/ARC 4	East Siberian Sea
Ship3	Bulk Carrier	95,758	1A/ARC 4	East Siberian Sea

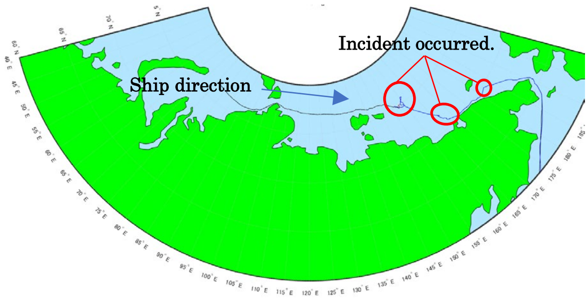

Figure 2.　Ship track of incident case

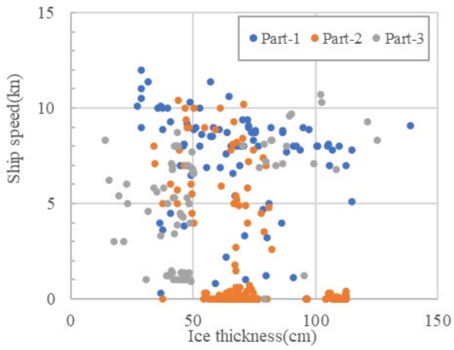

Figure-3　Ice thickness and ship speed

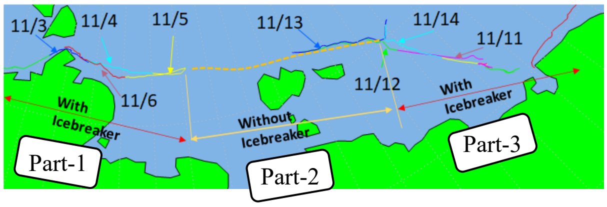

Figure-4　Navigation record with and without icebreaker

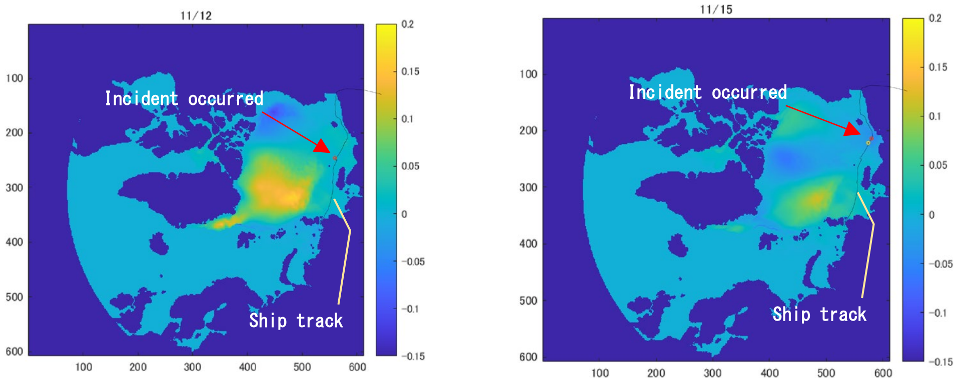

Figure-5　Sea ice convergence factor

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