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# Sea ice prediction and construction of an ice navigation support system for the Arctic sea routes

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## ABSTRACT

The recent retreat of summer sea ice in the Arctic Ocean is one of the most significant environmental issues. On the other hand, it also increases the possibility of commercial use of the Arctic Ocean as a new shipping route. Upon such circumstances, the Ministry of Education, Culture, Sports, Science and Technology, Japan commenced comprehensive 5-year research program on the Arctic climate system and its global influence. The program contains 9 research projects including a study on the sea ice prediction and construction of an ice navigation system. This study covers ice prediction, ice monitoring, ship-ice interaction, ship icing, navigation scenario and economic evaluation. This paper describes the overview of this research project, and some details on the progress of sea ice prediction method. One method is to estimate the summer sea ice distribution from the preceding winter ice motion which can be obtained by analyzing satellite remote sensing data. The other is numerical computation using ice-ocean coupled model. The study is still progressing but the satisfactory results have been obtained so far.

## INTRODUCTION

With reduction of the sea ice in the summer Arctic Ocean, a reality is increasing for the use of the Arctic Ocean as a commercial sea route. To this goal, the cooperation across the boundaries among science, engineering and economics is indispensable through understanding of ice condition and its prediction, understanding of influence on ship hull during ice navigation, planning of effective transportation, and so on. Therefore, as one of the GRENE research program [1] under the Ministry of Education, Culture, Sports, Science and Technology, we started a new 5-year research project "Sea ice prediction and construction of ice navigation support system for the Arctic sea routes" since fiscal year 2011. 11 experts participated in this research project from 9 organizations.

The aim of this research is to create a forecast system and a criterion of judgment required for use of the Arctic sea routes including Northeast Passage (Northern Sea Route) and Northwest Passage. The research is being performed with the following 4 subthemes.

1. Development of the prediction technique of sea ice distribution: put emphasis on the short-term forecast of the one-week scale using a high resolution numerical model, and the

middle-term forecast of several-month scale using satellite data and a statistics model. This subtheme is being executed with the results of the following three subthemes taken into account for the practical ice prediction to support the ship navigation.

2. Ice monitoring along the routes: develop an ice monitoring methodology using the sea ice information including ice area, thickness, convergence, divergence, etc., acquired from satellite remote sensing. The research for navigation support is being executed to lead to ice navigation and cruise safety index.

3. Understanding of the influence of cold region sea conditions on vessels: study the dynamics of ship-ice contact and hull icing.

4. Design of navigation scenario with the economics taken into account.

By collecting the results of these subthemes, we will develop the navigation support system for the propriety judgment and efficient use of the Arctic sea route.

Although the project overview is introduced later, this paper mainly describes the 1st item, i.e. prediction of ice conditions. When we think about the application of ice prediction to the commercial shipping, 3 categories of ice predictions are necessary. One is short-term prediction, i.e. around 1-week prediction. This is needed for ship navigation after entering the Arctic Ocean. Second is middle-term prediction, i.e. to predict roughly the summer sea ice distribution by the end of preceding spring. This is needed for decision of taking the Arctic sea route or normal southern route. Third is long-term prediction, i.e. several 10 years prediction. This is needed for economic evaluation and decision of large investments, e.g. construction of new vessels. It is considered that the first and third predictions can be realized by improving numerical model predictions. But the second one is still very difficult issue for numerical forecast methodology. On this matter, we develop a statistical method based on winter ice motion derived from satellite remote sensing observation.

## MIDDLE-TERM ICE PREDICTION BY SATTELITE REMOTE SENSING DATA

Satellite passive microwave sensor provides daily ice images for the whole Arctic Ocean even in winter. By comparing two images of adjacent two days, we can calculate the ice velocities based on maximum cross correlation method [2, 3]. By

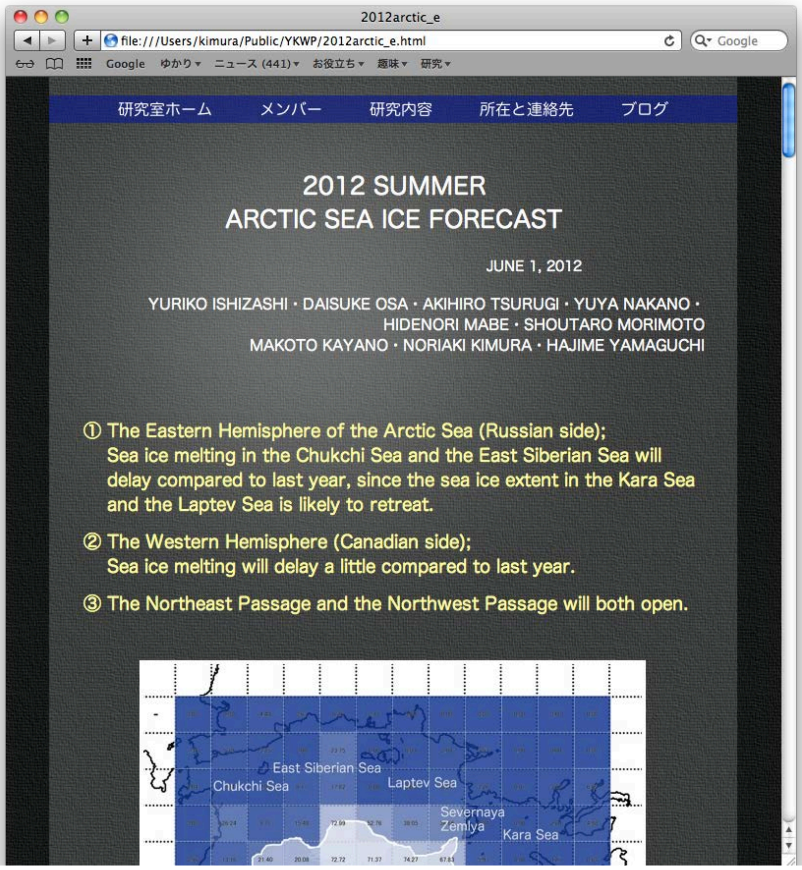


Fig. 1 Middle-term Arctic sea ice forecast through web page
http://www.1.k.u-tokyo.ac.jp/YKWP/2012arctic_e.html

integrating ice velocities, we can obtain the ice motion from winter to spring. Thin ice must be formed in the ice diverging area, and likely to melt in summer. Thus we can roughly estimate the summer ice distribution (Fig.1).

## NUMERICAL PREDICTION

An ice-ocean coupled model developed for the Sea of Okhotsk [4] is applied for the Arctic Ocean. Ocean part is based on a sigma-coordinate primitive equations POM, Princeton Ocean Model. Ice dynamic model is based on elastic-viscous-plastic one with the extension to floe collision rheology near ice edge, and ice thermodynamic model is zero-layer model with snow effect taken into account. The atmospheric forcing is given by the ERA-interim project six hourly re-analysis databases. Some more details are described elsewhere [5].
The whole Arctic Ocean is computed with coarse grids (about 25km x 25km) to investigate the model basic performance and to improve the code. After several improvements of the details, the computed results can be compared fairly well with the observations (Fig.2)

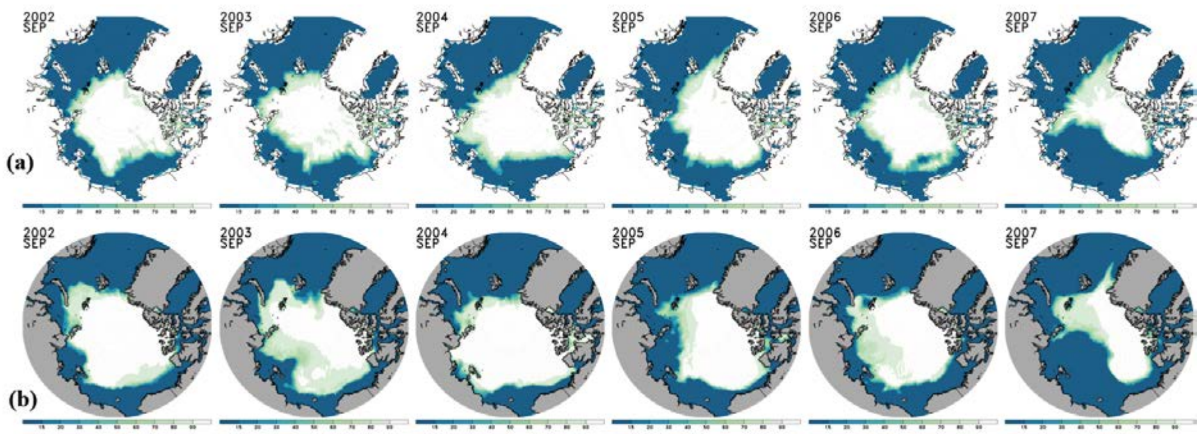


Fig. 2 September mean sea ice concentration from year 2002 to 2007. (a) HadISST observational concentration. (b) Numerical model computation.

Then the code is modified to a regional model with about 2.5km x 2.5km grids for short-term

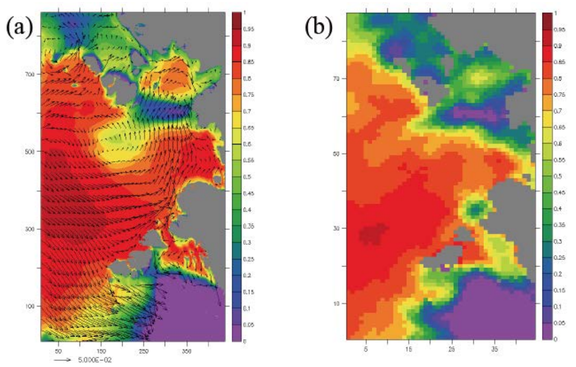


Fig. 4 Averaged sea ice concentration during 20-Jul-04 to 17-Aug-04. (a) Model predicted ice concentration and the ice velocity [m/s]. (b) AMSR-E satellite observed ice concentration.

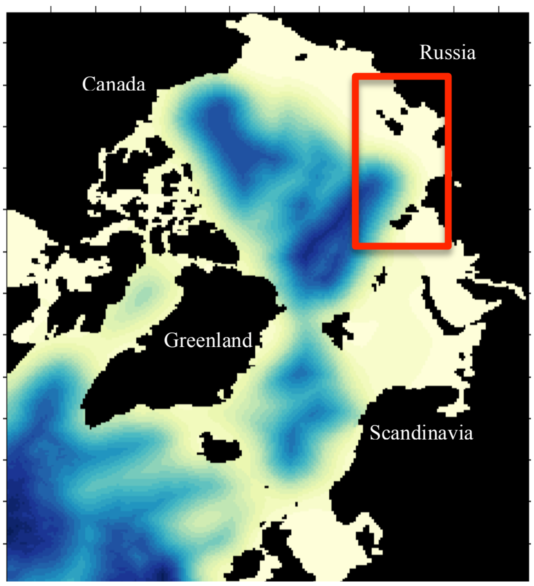


Fig. 3 Computational domain of regional model (rectangular) and bathymetry

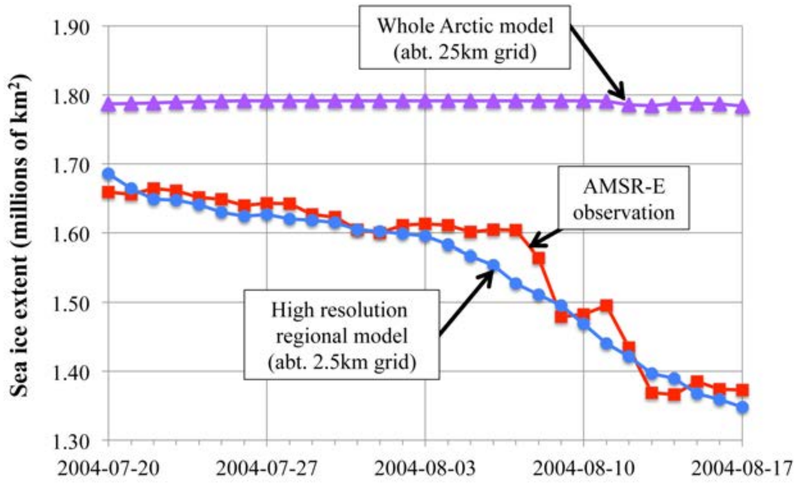


Fig. 5 Comparison of sea ice extents between coarse grid computation (Whole Arctic model), fine grid computation (regional model) and satellite observation (AMSR-E) during 20-Jul-04 to 17-Aug-04. Area covered with more than 10% ice concentration is taken into comparison.

prediction (Fig.3). Figure 4 compares the ice distribution around the Laptev Sea, and figure 5 compares the variation of sea ice extent among coarse grid computation (Whole Arctic model), fine grid computation (regional model) and satellite remote sensing observation (AMSR-E). The coarse grid computation cannot reproduce ice reduction in this season, while the fine grid computation can predict it although the computation cannot follow a high-frequency variation yet. There are two reasons for this discrepancy between coarse and fine grid computations. The fine grid computation well expresses the ice-albedo feedback process, which accelerates the ice melting in summer. The other reason is ice-ocean interaction. The fine grid computation reproduces meso-scale eddies in the ocean. The eddy draws out the ice from its main body and melts it (Fig.6). The ice melt supplies low-salinity cold water on the ocean surface, activating eddy production due to baroclinic instability.

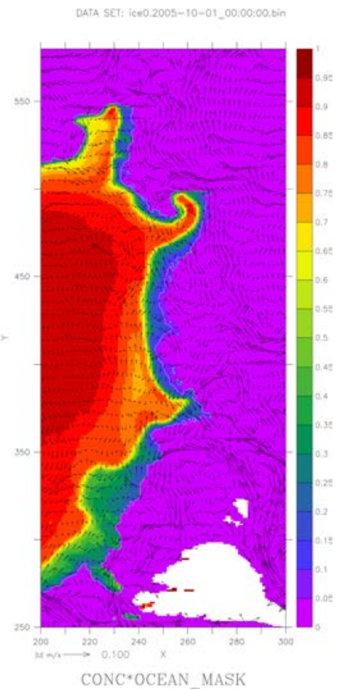


Fig. 6 Example of snapshots of ice-eddy interaction: Oct. 1, 2005. Color bar = sea ice concentration; Vectors = surface ocean current; North of Sevelnaya Zemlya Islands.

## PROJECT OVERVIEW

The GRENE Arctic research program is running 7 specific research projects, 7th of which is studying sea ice and ocean, and consists of 3 sub-projects. The research project described in this paper is one of these 3 sub-projects. Figure 7 shows the relationships among subthemes in the project, 7-1, and related 2 projects, 7-2 and -3. The project, 7-1, is being carried out by the following members:

**Principal Investigator**

- Hajime Yamaguchi, Graduate School of Frontier Sciences, The University of Tokyo, Ice forecasting system and project supervision.

**Member Researchers**

- Hiromitsu Kitagawa, Ocean Policy Research Foundation, Ship icing and advice for the whole project.
- Noriaki Kimura, Graduate School of Frontier

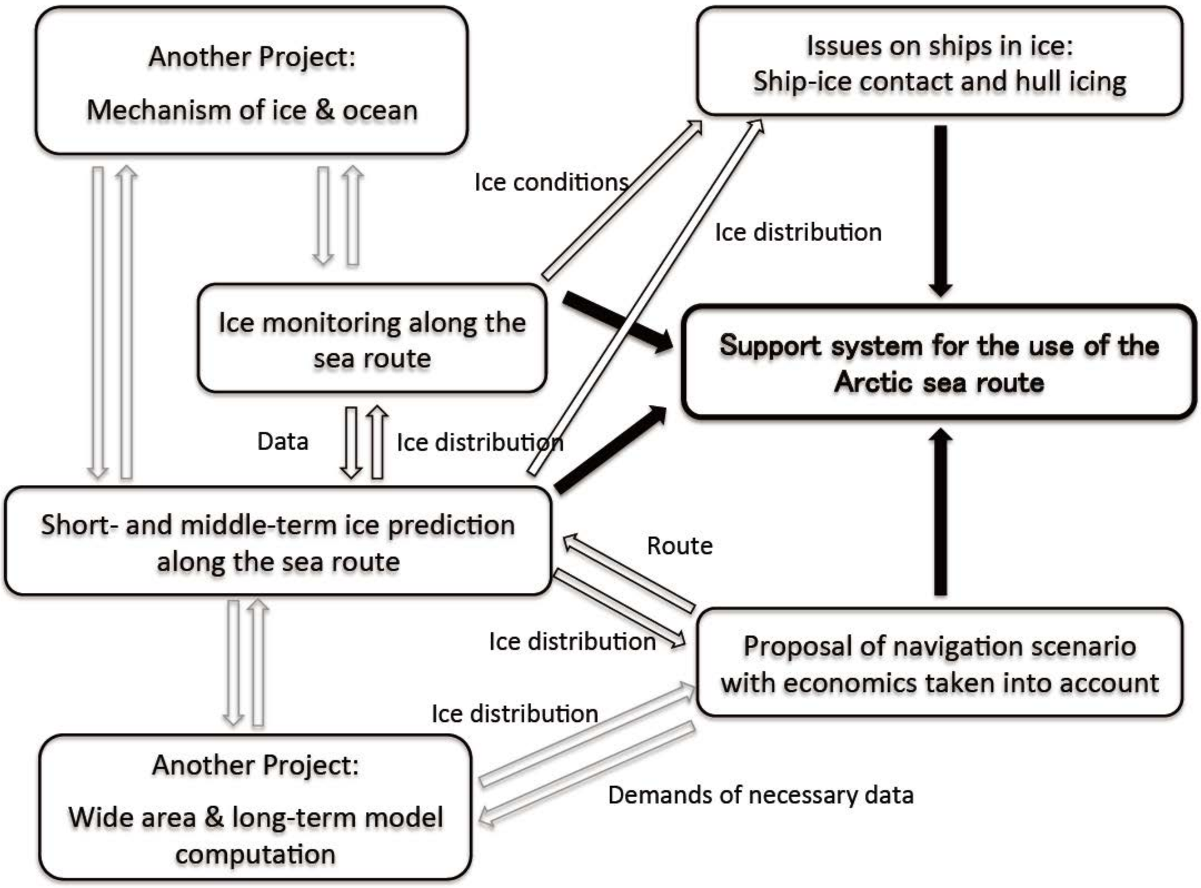


Fig. 7 Overview of research project "Sea ice prediction and construction of an ice navigation system for the Arctic sea routes"

Sciences, The University of Tokyo, Analysis of ice data and ice forecasting system.

- Jun Ono, National Institute of Polar Research / The University of Tokyo, Ice forecasting system.
- Genki Sagawa, Global Ice Center, Weathernews Inc., Ice monitoring and ice forecasting system.
- Kazutaka Tateyama, Kitami Institute of Technology, Ice monitoring and navigation safety index.
- Toshiyuki Takagi, Kushiro National College of Technology, Ice navigation.
- Akihisa Konno, Kogakuin University, Ship performance and safety assessment of ice navigation.
- Toshihiro Ozeki, Hokkaido University of Education Sapporo, Ship icing.
- Hijiri Adachi, Snow and Ice Research Center, National Research Institute for Earth Science and Disaster Prevention, Ship icing.
- Natsuhiko Otsuka, North Japan Port Consultant, Co. Ltd., Assessment of availability of the Arctic sea routes.

**Related member in the GRENE Steering Committee**

- Koh Izumiyama, North Japan Port Consultant, Co. Ltd.

The progress of the whole project has been reported in special sessions of two international symposia [6, 7]. The part, "Ice monitoring along the sea route", in Fig.7 contains the development and improvement of satellite remote sensing algorithms for ice thickness and melt ponds (Fig.8) which are next targets of remote sensing technique since ice concentration algorithms are almost established. Sea truth data are being collected by on-board simultaneous measurements using an electro-magnetic induction ice profiler and a passive microwave radiometer which is the same type as launched in an artificial satellite. These on-board measurements have been carried out at the Antarctica, the Sea of Okhotsk, the Northwest Passage (Fig.9) and the Canada Basin (Fig.10). The measurement along the Northeast Passage is also planned. This subtheme also contains a study of optimum route search in ice navigation using ant colony optimization method and reinforced learning one. Figure 11 is an example of the results of no-ice-touch route search based on radar image.

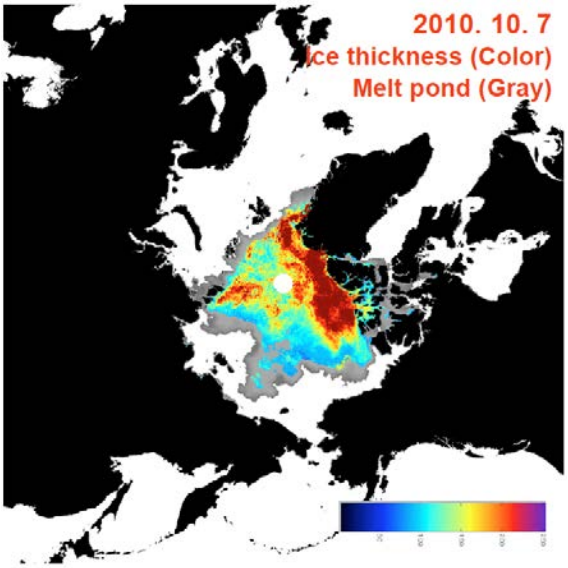


Fig. 8 Sea ice thickness and melt pond distribution in the Arctic Ocean calculated from AMSR-E sensor data on Oct 7, 2010. Color means ice thickness and gray means surface melting area. [8]


Fig. 9 Cruise track of JOIS2012 Leg.1 observation along the Northwest Passage (July 20 - Aug. 2, 2012) [9]

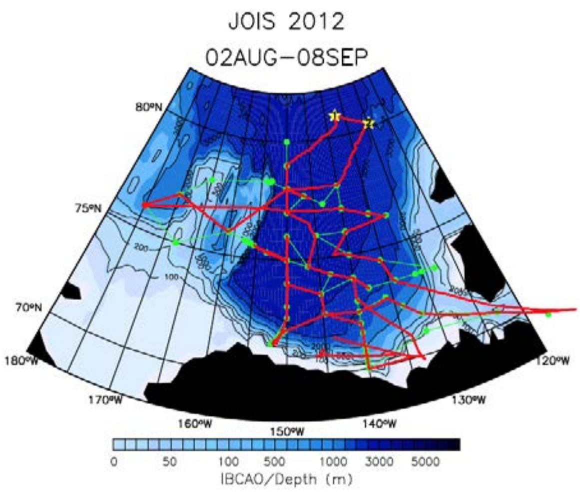


Fig. 10 Cruise track (red line) of JOIS2012 Leg. 2 observation in the Canada Basin (Aug. 2 - Sep. 8, 2012) [10]

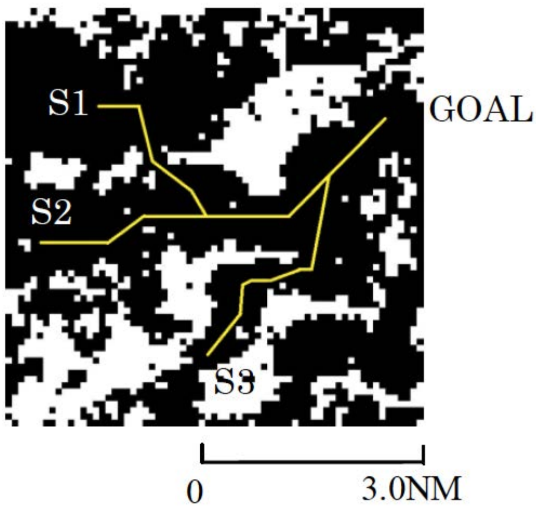


Fig. 11 Example of optimum route search results with no-ice-touch condition based on radar image. White = digitized ice area; Black = digitized open-water area. [11]

The part of "Issues on ships in ice" in Fig.7 consists of two studies on ice-ship interaction and ship icing, respectively. The ice-ship interaction study aims at developing a numerical simulator of interaction between floating ice pieces and ship hull by extending a simulator on brash ice channel [12]. The ship icing study contains several on-board simultaneous measurements of spray particles and ship motion [13] to clarify the mechanism of ship icing, and laboratory and field experiments to develop a countermeasure. The progress of the final part of "Proposal of navigation scenario" in Fig.7 is also presented at this conference [14].

## CONCLUDING REMARKS

The ongoing research project "Sea ice prediction and construction of an ice navigation support system for the Arctic sea routes" is briefly explained. Also, the most recent results of sea ice prediction work with the Arctic shipping taken into consideration are described. The short-term and long-term predictions are performed by numerical method. The middle-term prediction is based on a statistical method using satellite remote sensing data. The study is still in the developing stage but the results so far are satisfactory:
Summer ice distribution is well predicted by the statistical method based on winter ice motion. Trial forecast through web page has already been done. The work to improve the prediction accuracy both in area and time will be continued.
Numerical codes for the Arctic Ocean have been developed by hindcast computations. The whole Arctic model well reproduced the overall trends of long-term change of the Arctic sea ice. The high-resolution regional model for short-term prediction revealed the significant importance of ice-albedo feedback and ice-ocean interaction for precise ice prediction. The work to improve the accuracy will be continued, and also the methodology to utilize the computed results for the ship navigation will be discussed in future.


## ACKNOWLDGEMENTS

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