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A high-resolution hindcast study for the Northern Sea Route

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ABSTRACT
Rapid decrease of summer sea ice in the Arctic Ocean has been extending the navigation period in the Northern Sea Route (NSR). In this regard, precise ice distribution prediction is one of key issues to realize safe and efficient navigation in the Arctic Ocean. In general, however, most of the available numerical models have shown high uncertainties in the short-term and narrow-area predictions, especially marginal ice zones like NSR. In this study, therefore, we predicted the short-term sea ice conditions in Arctic sea routes using meso-scale eddy resolving high-resolution ice-ocean coupled model (ice-POM) with explicitly treating the ice floe collision in the marginal ice zones. Results from a whole Arctic coarser resolution (about 25km) model demonstrate reasonable performance for seasonal and interannual variations in comparison to the observations. High-resolution (about 2.5km) regional model showed the better sea ice extent variations along NSR compared to the coarser resolution model, because of the better representation of ice-albedo feedback process and ice-eddy interaction process in high-resolution model.

KEY WORDS: Arctic sea ice; Numerical simulation; Floe collision; Arctic sea routes.

INTRODUCTION

Satellite observations have shown the rapid decrease of sea ice in the Arctic Ocean. However, retreat of summer sea ice in the Arctic Ocean attracts the interest of exploring the Arctic areas. Such as natural resource exploitation and commercial shipment through the Arctic sea routes (ASR). Advantages of ASR are shorter distance; according to the surveys Arctic sea routes can shorten the travel distance about 40% from the existing southern sea routes. And the existence of two routes instead of the one sole southern route will represent the tremendous boost to the security of international shipping. Therefore ASRs are considered to be efficient, economical, and safe passages for transportation industry. However, in ice-covered areas detecting sea ice conditions are needed to protect ships and minimize the damage to coastal facilities along the ASR.

Numerical modeling of sea ice has become one of the important instruments for ice monitoring, understanding past conditions and explaining recently observed changers and future predictions in Arctic Ocean.

First time of the history, collaboration research between Japan, Norway, and Russia advanced the International Northern Sea Route Programme (INSROP) to examine the possibilities of utilizing the NSR as an international commercial sea route from 1993 to 1999 (Kitagawa et al., 2001). INSROP has abled to develop and demonstrate the technical, ecological, environmental, economic, political, and strategic aspects of NSR. But unfortunately INSROP project has not focused on developing a rigorous sea ice prediction method along the NSR; instead sea ice prediction was depending on the simple numerical predictions and satellite information. Since, 2001 the International Arctic Ocean Model Intercomparison Project (AOMPI) has focused on improving Arctic regional models and investigated many aspects of ocean and sea ice changers (Holloway et al. 2007). However, In general most AOMIP numerical models underestimate the amount of thicker ice (h >2m) and over estimate the amount of thinner ice (h <2m) (Proshutinsky et al. 2011).

Therefore accurate prediction method is an argent need for navigating in ASR. Therefore in this study we aim to predict the short-term sea ice condition in Arctic sea routes using meso-scale eddy resolving high-resolution ice-ocean coupled model.

MODEL CONFIGURATIONS

Almost all-existing sea ice prediction models are based on the continuum approach in ice dynamic processes. On scale much larger than floe size, continuum approximation is commonly assumed. Advantages of the continuum model are simplicity, low computational cost, and good description of large-scale sea-ice behavior. However, when dealing with an ice prediction in a small region consists of sea ice margin such as the northeastern passage, it is not realistic to treat sea ice extent as a continuum body because the sea ice consists of discrete ice floes. Therefore, a model that takes account of the ice discrete characteristics is needed for higher resolution forecasting. In this situation, we introduce the flow collision rheology of (Sagawa 2007) into the conventional elastic-viscous-plastic rheology of (Hunke 2001). Also we introduce the sub grid scale ice motion (Lagrangian movements) into the sea ice dynamics to minimize the sea ice diffusion and improve the accuracy of ice edge locations in ice-POM model.

Ocean part of the ice-POM model is a parallel, free-surface, sigma-coordinate, primitive equations ocean modeling code based on the Princeton Ocean Model (POM). Thermodynamic part of this ice-ocean coupled model is based on (Parkinson & Washington 1979) and adopted the (Semtner 1976) zero-layer model. The radiation boundary condition is applied at the open lateral boundaries and no-slip boundary condition is used along the coastlines. To avoid the singularity at the North Pole the whole grid is rotated to the equator.

Figure 1 shows the whole Arctic and high-resolution regional model domains with bottom topography based on the Earth Topography one-minute Gridded Elevation Dataset (ETOPO1). Figure 1(a) red rectangles show the high-resolution domains in the whole Arctic model and color bar denotes the model bathymetries in meters. Figure 1(b) covers the region with 50E:165E longitude and 68N:85.5N latitudes. That consists of Laptev Sea, part of Kara and East Siberian Seas.

The atmospheric forcings are given by the ERA-interim project six hourly databases. The Pacific water inflow with sinusoidal seasonal cycle is provided at the Bering Strait based on the hydrographic observation of (Woodgate, 2005).

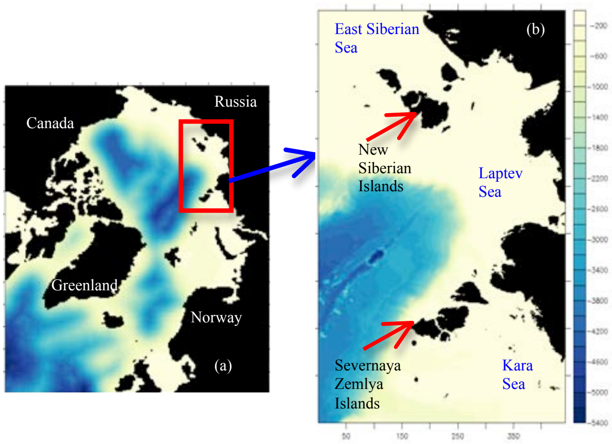

Figure 1 Model bathymetries. (a) Whole Arctic model and red rectangle denotes the corresponding high-resolution domains in the Northern Sea Route, (b) High-resolution regional model consist of part of East Siberian sea, Kara sea and Laptev sea (LS)

The time integration started from the steady state with a climatological temperature and salinity field provided by (PHC3.0).

First, model was spun up for 15 years by providing the year 2000 atmospheric data cyclically. Entire model domain reached the equilibrium after the 15 years spin up. Then the model is integrated from year 2000 to 2012 with ERA-interim realistic atmospheric forcing.

ICE-POM MODEL REPRODUCIBILITY

For the whole Arctic simulation spatial resolution is set to 25km×25km in horizontal plane and 33 sigma layers in the vertical direction. Figure 2(a) and 2(b) show the September mean model sea ice concentrations comparison with corresponding months observational sea ice concentrations obtained from Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST). By looking at the qualitative comparison shown in Figure 2 following observations are made. Overall agreement of model simulated and observational September Arctic sea ice concentrations are quantitatively reasonable. The negative trend of September Arctic sea ice extents, year 2007 minimum sea ice concentrations, and year 2005 opening of the Northeastern Passage are well captured with simulated results. However we have believed that the reason for discrepancy of the model and the observation sea ice extent is due to the simplified thermodynamics model (especially constant albedos and disregards of melt pond), coarseness of model grids and lack of reproducibility of multi year high thickness ice in our model. However overall agreement in concentrations and extents are reasonable with observations.

In addition to concentration we have compared the reproducibility of the model sea ice extent, sea ice thickness and sea ice drift velocity with the observations. The model results have revealed the ice-POM model can be used to reproduce the Arctic sea ice environment accurately.

SHORT-TERM FORECAST FOR THE ARCTIC SEA ROUTE

As shown in above section, our whole Arctic model was able to capture the long-term trend of sea ice conditions accurately. But later we have revealed that the whole Arctic coarser resolution model cannot be used to investigate the fine details of sea ice dynamics like ice edge positions and extents accurately for short-term predictions. Therefore we have constructed the high-resolution model, 2.5km×2.5km in horizontal plane and 33 sigma layers in the vertical direction. Initial conditions and lateral boundary conditions are given by using output of the whole Arctic coarser resolution model.

As shown in Figure 3, year 2004 (NSR closed year) and 2005 (NSR opened year) model predicted sea ice extent is compared with the satellite observation (AMSR-E) sea ice extents. The computations were performed from each year 20th July to 17th August. The model sea ice extent is varied from 1.7 millions of square kilometers to 1.3 millions of square kilometers in year 2004 and 1.5 millions of square kilometers to 0.9 millions of square kilometers in year 2005 due to the thermodynamics and dynamics activities. The overall agreement between modeled and observed sea ice extent is very well agreed with each other.

By considering all the qualitative and quantitative comparisons of regional model results we have come up with following conclusions. The coarse grid computation cannot be used to predict the sea ice variations in summer seasons accurately. But fine grid computation can predict the sea ice variation accurately with satellite observations. However, even the high-resolution computations cannot

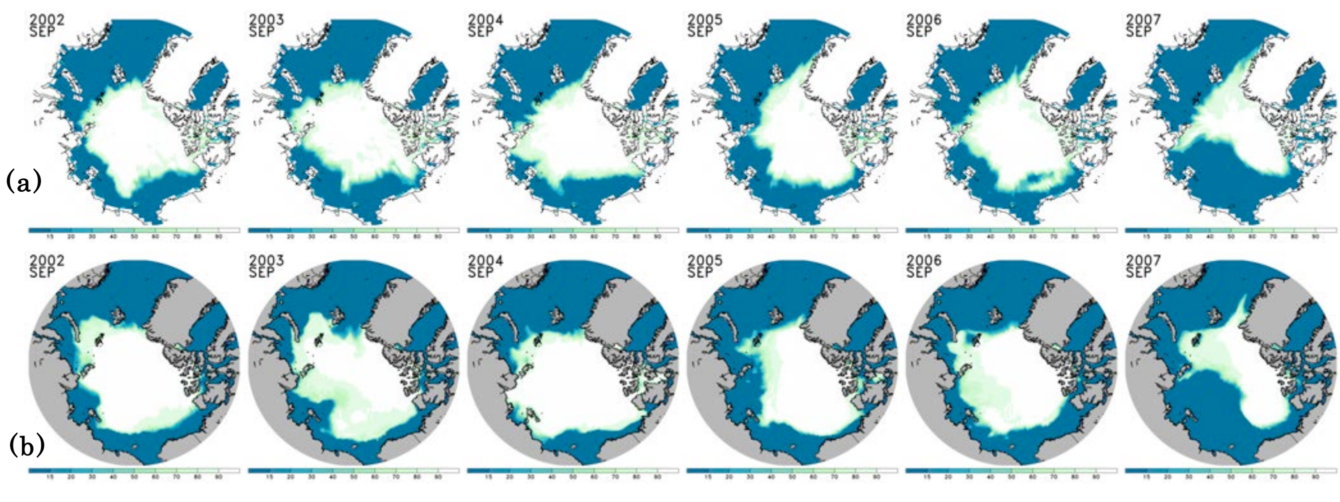

Figure 2 September mean sea ice concentration from year 2002 to 2007. (a) HadISST observational concentration. (b) Numerical model predicted sea ice concentration

follow the high-frequency variations yet.

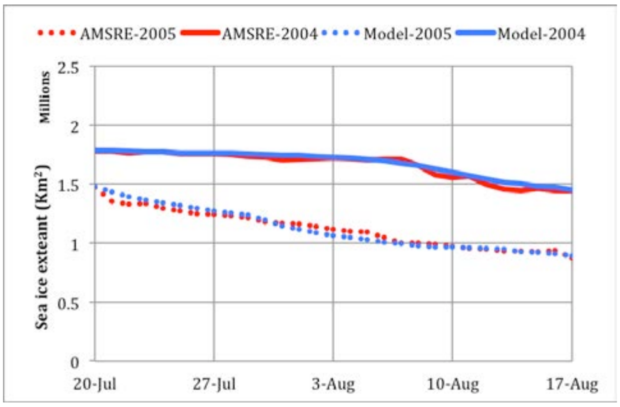

Figure 3 Comparison of satellite observation (AMSR-E) sea ice extent and model predicted sea ice extents in 20-Jul to 17-Aug. Area covered with more than 15% concentration is taken into comparison.

There are several possible reasons for discrepancy results between coarser and high-resolution grid computations. First, the high-resolution grid computation well expresses the ice-albedo feedback process, which accelerates the ice melting in spring and summer seasons. If the ice is broken up, the areas of open water between floes absorb a great deal of solar energy in warm months. That energy can be transferred both to the sides of the floes and underneath the floes, promoting further melt.

The next one is small-scale sea ice dynamics was correctly captured with high-resolution models compared to the coarser gird models. The wind or ocean on sea ice either push the ice together, resulting in a smaller extent, or spread it out, resulting in larger expanses of sea ice at a lower density. These processes are known as convergence and divergence, respectively. Correctly resolved converging and diverging process of sea ice have improved the sea ice edge locations and extents.

CONCLUSIONS

In this study, the ice-ocean coupled system was investigated using a mesoscale eddy resolving model. The high-resolution model has reproduced a reasonable sea ice extent and concentrations compared with the observational data because of the better representation of ice-albedo feedback process and ice-eddy interaction process.

In conclusion, in terms of accurate forecasting sea ice using high-resolution ice-ocean coupled model we have to input the appropriate initial conditions and realistic forcing data. At this point lack of observational sea ice data and coarseness of the reanalysis forcing data are the key bottlenecks for making accurate forecasting and validating the model results in Arctic areas. However, the present result (hindcast) has shown that our model can be used to forecast the short-term sea ice fairly accurately despite those limitations.

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REFERENCES

Holloway, G. et al, 2007: Water properties and circulation in Arctic Ocean models. *Journal of Geophysical Research*, **112**, pp C04S03.

Hunke, E. C., 2001: Viscous–Plastic Sea Ice Dynamics with the EVP Model: Linearization Issues. *Journal of Computational Physics*, **170**, pp 18–38

Kitagawa, H., N. Ono, H. Yamaguchi, K. Izumiyama, and K. Kamesaki, 2001: *Northern Sea Route. Shortest Sea Route Linking East Asia and Europe.*

Parkinson, C. L., and W. M. Washington, 1979: A large-scale numerical model of sea ice. *Journal of Geophysical Research*, **84**, pp 311.

Proshutinsky, A. and Coauthors, 2011: Recent Advances in Arctic Ocean Studies Employing Models from the Arctic Ocean Model Intercomparison Project. *Oceanography*, **24**, pp 102–113

Sagawa, G., 2007. Development of ice dynamic model that takes account of floe collision and its validation in numerical sea ice forecast in the Sea of Okhotsk.

Semtner, A. J., 1976: A Model for the Thermodynamic Growth of Sea Ice in Numerical Investigations of Climate. *Journal of Physical Oceanography*, **6**, pp 379–389.

Woodgate, R.A., 2005. Monthly temperature, salinity, and transport variability of the Bering Strait through flow. *Geophys. Res. Lett.* 32, pp L04601.