Numerical investigation of sea ice prediction to support ice navigation in the Northern Sea route

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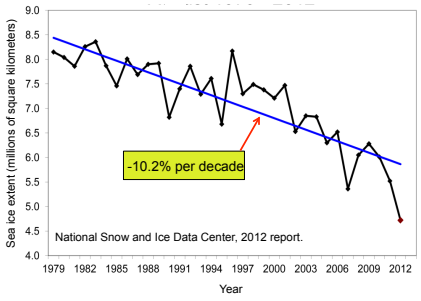
GRENE-Arctic

Introduction

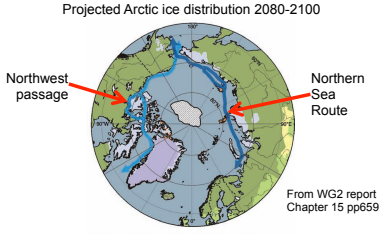
Rapid decrease of summer sea ice in the Arctic Ocean has been extending the navigation period in the Northern Sea Route(NSR).



Monthly average Arctic sea ice extent August 1979-2012

The passages through the Arctic Ocean are the shortest sea routes from North American and European harbors to Far East Asian harbors. In this regard, precise ice distribution prediction is one of the key issues to realize safe and efficient navigation in the Arctic Ocean.

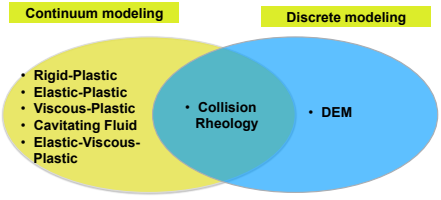
Projected Arctic ice distribution 2080-2100



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 ASR.

Short term	• About 1 week • Decision of navigation route after entering the ice area
Medium term	• Several months • Decision of taking the Arctic route or normal route
Long term	• 10-30 years • Decision of new vessel construction

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.



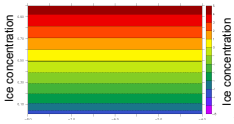
Ice-ocean coupled model description

Ice model

- ❑ Ice model based on Sagawa(2007), Fujisaki et al. (2010), and De Silva (2013)
- ❑ Two state variables (mean thickness and concentration)
- ❑ Semi Lagrangian advection scheme
- ❑ Ice collision rheology

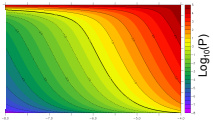
$$\frac{1}{E}\frac{\partial \sigma_{ij}}{\partial t}+\frac{1}{2\eta}\sigma_{ij}+\frac{\eta-\zeta}{4\eta\zeta}\sigma_{kk}\delta_{ij}+\frac{P}{4\zeta}\delta_{ij}=\dot{\varepsilon}_{ij}$$

VP & EVP rheology ice strength (Hibler, 1979; Hunke, 2001)



$$P=P^{*}hA\exp\left(-C\left(1-A\right)\right)$$

Collision rheology ice strength (Sagawa, 2007)



$$P=\frac{P^{*}_{col}\alpha^{(1-x)}hA}{\max\left(A^{-1}-\frac{2\sqrt{3}}{\pi}\gamma^{-1},d\right)}\Delta^{2x}$$

$$x=1-\exp\left(-C_{col}\left(\frac{\pi}{2\sqrt{3}}\gamma-A\right)\right)$$

$$\alpha=\frac{P^{*}}{P^{*}_{pol}}dA_{\max}\exp\left(-C\left(1-A_{\max}\right)\right)$$

Ocean model

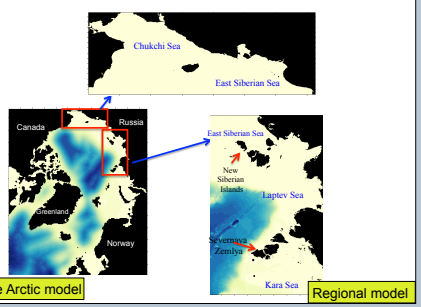
- ❑ Ocean model based on Princeton Ocean Model (POM)
  - ○ 3D, Primitive Eqs. and Continuum Eq. with a hydrostatic approximation
  - ○ Vertical 33 sigma layers
- ❑ Lateral boundary conditions
  - ○ Radiation and no-slip
  - ○ Volume, T, S at Bering Strait Woodgate et al. (2005a)
- ❑ Bathymetry ETOPO 1

Thermodynamics model

- ❑ Based on 0-layer thermodynamics model (Semtner 1976)
- ❑ Calculation of Heat fluxes (Parkinson and Washington, 1979)
- ❑ Calculation thickness change by solving heat balance at upper and lower sea-ice surfaces
- ❑ Snow effect (Zhang and Zhang, 2001)

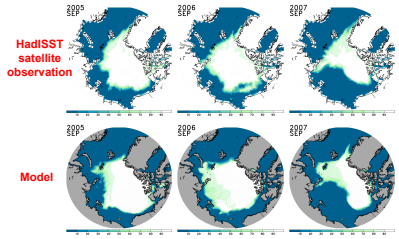
Goal and Model domains

1. Investigate the sea ice behavior in whole Arctic Ocean using ice-POM model
2. Investigate the meso-scale and large-scale sea ice behaviors in the Northern sea route using high-resolution regional models

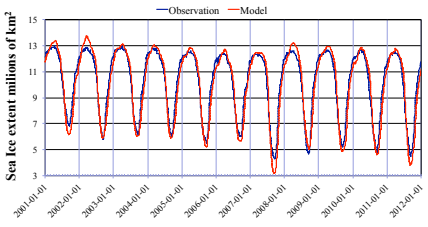


Model Results

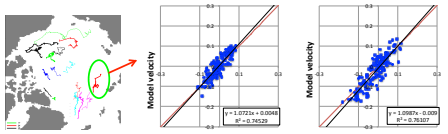
HadISST observation and model September ice concentration



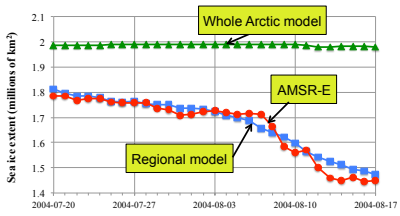
Time series of model and observational ice extent from 2001-2011



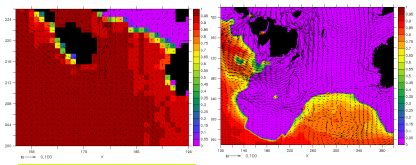
Comparison of the observed and simulated sea-ice velocities



High-resolution regional model sea ice extent comparison (off Laptev Sea)



Sea ice concentration and average top 100m ocean velocity on 2004-09-13



Conclusion

- Successfully resolved numerical instability issues associated with collision rheology
- Whole Arctic model sea ice extent, thickness and velocity reproducibility are very reasonable.
- High-resolution model reproduced the sea ice extent and concentrations reasonably with observation
- Ice collision rheology play an significant role in the Arctic sea routes
- Meso-scale eddies and river runoff play an significant role in sea ice melting/freezing in Northern sea routes.