Improve ocean mixing caused by subgrid-scale brine rejection using multi-column ocean grid in a climate model

Meibing Jin, Jennifer Hutchings, Yusuke Kawaguchi and Takashi Kikuchi

International Arctic Research Center (IARC), University of Alaska Fairbanks, USA
Japan Agencyfor Marine-Earth Science and Technology (JAMSTEC), Japan

Abstract

Heterogeneous ice pack with sporadic narrow but long leads in the polar oceans was unresolved in typical climate model grid. Although multi-category sea ice thickness distribution was used in one sea ice model grid to calculate separate heat, salt and tracer fluxes through each category, the ocean models use only single-column grid to communicate with the averaged fluxes from all categories. When the lead is resolved by the grid, the added salt at the sea surface will sink to the base of the mixed layer and then spread horizontally. When averaged at a climate-model grid size, this vertical distribution of added salt is lead-fraction dependent. When the lead is unresolved, the model errors were systematic leading to greater surface salinity and deeper mixed-layer depth (MLD). An empirical function was developed to revise the added-salt-related parameter *n* from being fixed to lead-fraction dependent. Application of this new scheme in climate model showed significant improvement in modeled wintertime salinity and MLD as compared to series of CTD data sets in 1997/1998 and 2006/2007. The results showed the most evident improvement in modeled MLD in the Arctic Basin, similar to that using a fixed n = 5, as recommended by the previous Arctic regional model study, in which the parameter n obtained is close to 5 due to the small lead fraction in the Arctic Basin in winter.

1. Introduction

In wintertime, Arctic Ocean is mostly covered by sea ice with only occasional appearance of long narrow open water regions with width of several meters to several kilometers surrounded by large ice floes. Maykut(1982) estimates that freezing in leads accounts for half of the total amount of new ice formation in the wintertime Arctic ocean, even though the total area of lead only accounts for a few percent of the whole ice-covered area (Figure 1a). In climate models, the sea ice is divided into several ice-thickness categories in each grid cell (about 30 to 50km horizontal resolution in the Arctic in current NCAR-CESM, depending on the grid schemes used, e.g., displaced NP, tri-polar or other orthogonal grid), while the ocean model has only one cell. Thus the different heat/salt flux in each ice category are averaged when applied to ocean model grid. Here we focus on assessing the impacts and implications of this simplification on the ocean mixing in the climate models and ways to parameterize the subgrid scale ocean mixing.

Problems with salinity gradient degradation was observed in ocean general circulation models in the Southern Ocean (Duffy and Caldeira, 1997 and Duffy et al. 1999). Implications include deeper MLD, saltier surface and impacts on vertical heat fluxes in the ocean and to the sea ice.

Parameterization in the following form of vertical distribution of added salinity in the upper mixed layer (Nguyen et al., 2009):

$$s(z) = \begin{cases} Az^n & if\ |z| \le |D_{sp}| \\ 0 & if\ |z| > |D_{sp}| \end{cases}$$

Questions to answer in this presentation:
1) The sub-grid scale mixing is due to the uneven distribution of lead fraction in a grid. How to link parameter n to lead fraction?
2) Application of the scheme in CESM.

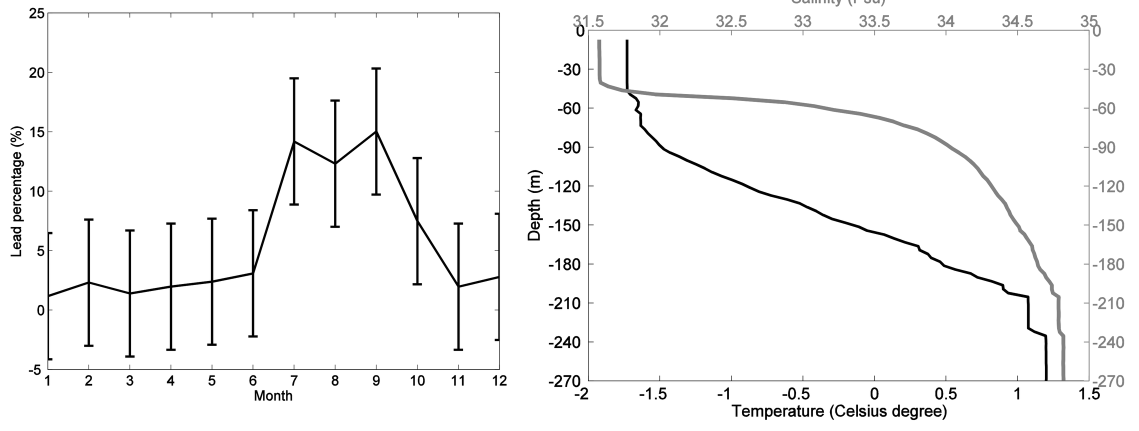


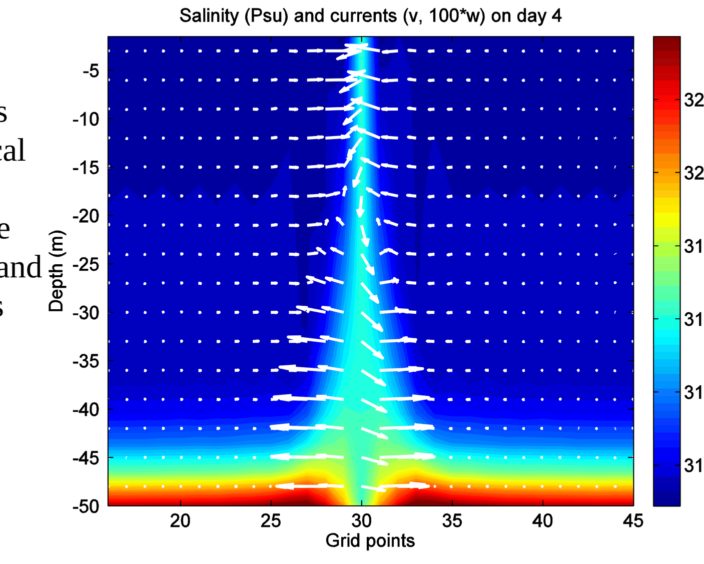
Fig. 1. (a) Monthly mean lead percentages from NIMBUS-7 SMMR and DMSP SSM/I passive microwave remote sensing data in the Arctic Ocean with one standard deviation error bar above and below the mean, and (b) the initial water temperature and salinity profiles on April 17 2011 for all cases.

2. Idealized model runs to assess model errors

Idealized model study using Princeton Ocean Model (POM) forced by brine rejection at the sea surface:

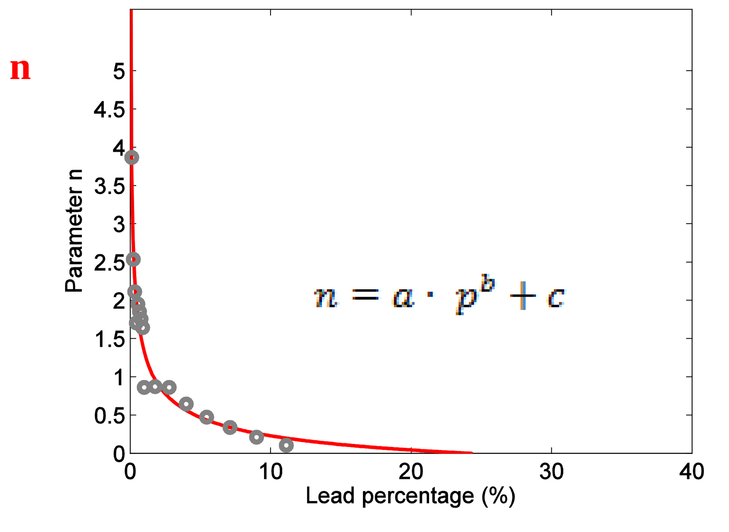
1) Model domain is 100*100 grid points with 1km or 30km horizontal resolution and 3m vertical resolution and 270m flat topography. The 1km grid model results are used as "true" solution to check errors in the 30km grid (representing climate model grid) model results.
2) Initial ocean T and S are set horizontally homogenous with T, S vertical profiles measured in NPEO April 2010 (figure 1b).

Fig. 2 A cross-lead section view of the modeled salinity and velocity on day 4. The model grid is 1km and the lead size is 1km x 8 km. The vertical velocity is multiplied by 100 in order to show directions. The salt flux in the lead can penetrate through the MLD (42.3m in the initial profile), and the horizontal spread of the salt plume increases with depth until it reaches the neutral buoyancy near the bottom of the MLD.



3. New parameterization scheme with n as function of lead percentage.

Estimate n using a number of 1km grid cases A01 ~A07 with different lead percentage. The pairs of lead percent (*p*) vs. parameter *n* (>0) are used to further best fit into a curve (Fig 3: Function of parameter n and lead percentage**).**

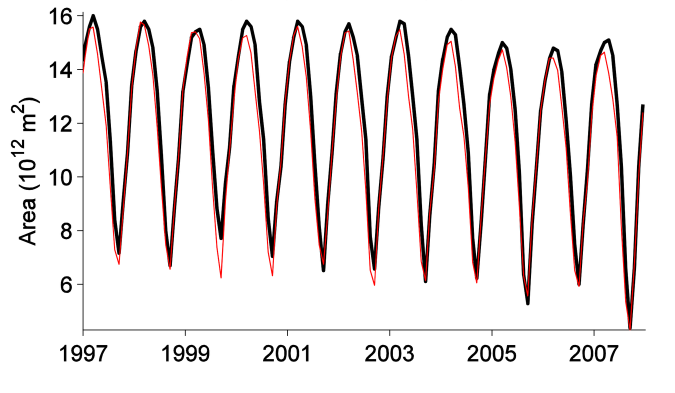


$$n = a \cdot p^b + c$$

4. CESM ice-ocean model runs with/without lead-dependent parameterization scheme

Model: global POP-CICE 1-degree
Time: 1988-2007

Fig. 2 Comparison of the monthly modeled and NSIDC sea ice extent in the northern hemisphere..



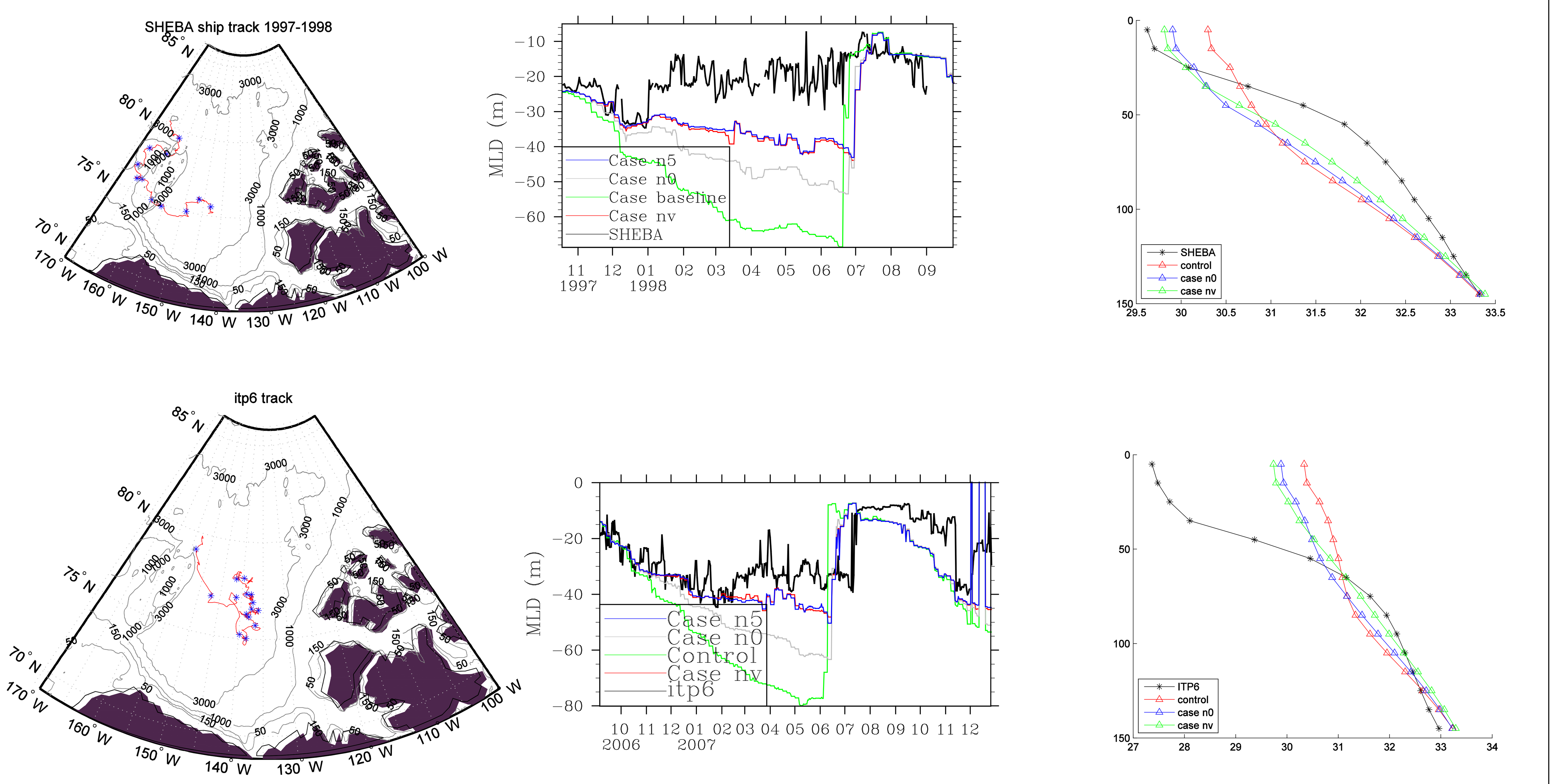


Figure 5:(a) SHEBA track; and (b) comparison of MLD from model cases and ITP data along the track. The '*' indicate the position on the first day of each month. c), d) are similar to a), b) but for ITP data.

Figure 6: Vertical salinity profiles of all cases: a) SHEBA, b) ITP.

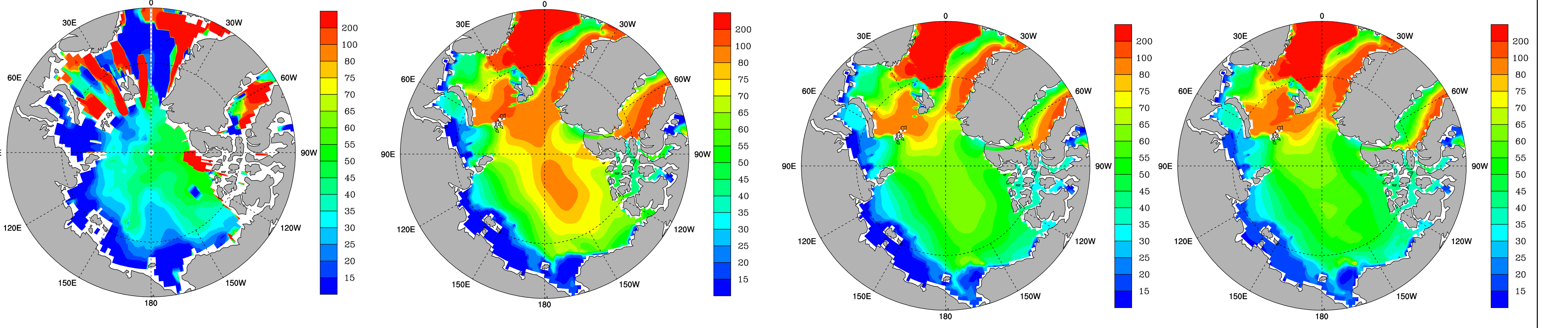


Figure 7: MLD in March: a) PHC 3.0, b) case n=0, c) case n=5,d) case n is lead-dependent. **Model experiments in CESM with lead-fraction dependent parameterization showed significant correction of model errors in simulating MLD and vertical salinity profile over the control run.**

5. Development of multi-column ocean grid (MCOG) for sub-grid scale ocean mixing under sea ice in CESM

Figure 7: A snap shot of vertical ocean mixing coefficient under lead and sea ice in one grid cell.

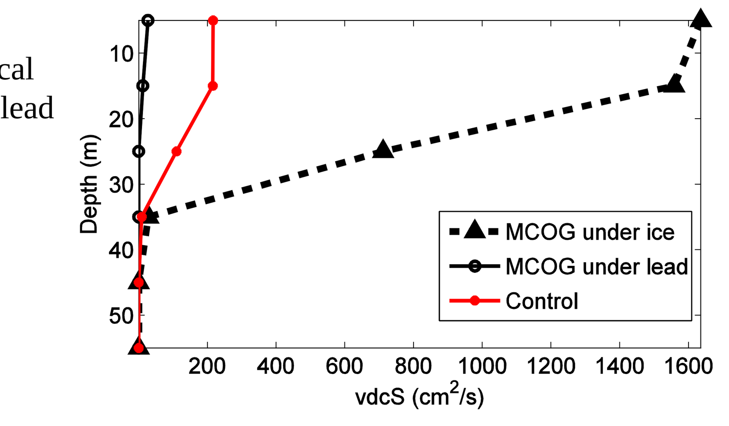
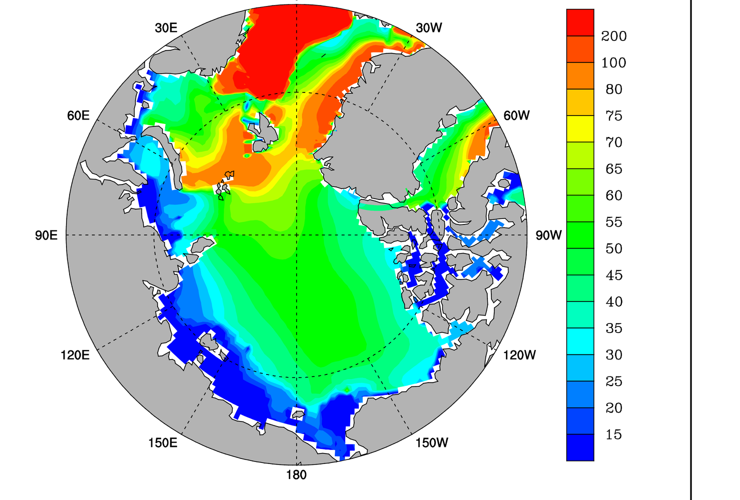


Figure 7: A snap shot of vertical ocean mixing coefficient under lead and sea ice in one grid cell.



Summary

Model experiments in CESM with lead-fraction dependent parameterization showed significant correction of model errors in simulating MLD and vertical salinity profile over the control run.

MCOG scheme is a directly solution to the sub-grid scale mixing problem. It can achieve significant model improvement as the parameterization and can be applied to tracers other that salinity.

Acknowledgements. This work was funded by NSF ARC-0652838, also supported by International Arctic Research Center through JAMSTEC-IARC Research Agreement.

References

Duffy, P., M. Eby, and A. Weaver, 1999. Effects of sinking of salt rejected during formation of sea ice on results of an ocean-atmosphere-sea ice climate model, Geophys. Res. Lett., 26(12), 1,739–1,742.

Jin M., J., Hutchings, Y., Kawaguchi, and T., Kikuchi. 2012. Ocean mixing with lead-dependent subgrid scale brine rejection parameterization in climate model. *Journal of Ocean University of China*, 11(4): 473-480, doi:10.1007/s11802-012-2094.

Nguyen, A. T., D. Menemenlis, and R. Kwok, 2009. Improved modeling of the Arctic halocline with a subgrid-scale brine rejection parameterization, J. Geophys. Res., 114, C11014, doi:10.1029/2008JC005121.