# Study on the Diagnostics and Projection of Ecosystem Change Associated with Global Change

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Seasonal and interannual variability in sinking flux of biogenic particles was reported by the multi-year bottom-tethered sediment trap measurements in the Northwind Abyssal Plain (Station NAP: 75°N, 162°W, 1,975 m water depth) of the western Arctic Chukchi Borderland. Whereas the trapped particle flux had an obvious peak with the dominance of sea ice-related diatom valve in August 2011, the observed particle flux was considerably suppressed throughout the summer season of 2012. In the present study, ice algal response to different hydrographic conditions was addressed using a pan-Arctic sea ice-ocean modeling approach. Sea ice ecosystem with an ice algal component was newly incorporated into the lower-trophic marine ecosystem model, which was previously coupled with a high-resolution (i.e., horizontal grid size of 5 km) ocean general circulation model. Seasonal experiments covering two year-long mooring periods indicated that primary productivity of ice algae around the Chukchi Borderland depended on basin-scale wind pattern through various processes. Easterly wind along the southern part of Beaufort High supplied high abundance of nutrient for euphotic zones of the NAP region via both surface Ekman transport of Chukchi shelf water and vertical turbulent mixing with underlying nutricline water as in 2011. In contrast, northwesterly wind flowing in the northern part of extended Siberian High transported oligotrophic water within the Beaufort Gyre circulation toward the NAP region as in 2012. The modeled ice algal biomass during the summer season certainly reflected the differences in nutrient distribution. The extension of year-long measurements is expected to help the illustration of more general features on the Arctic marine biological pump.

**Keywords**: Arctic Ocean, Northwind Abyssal Plain, ice algae model, primary production, wind pattern

## 1. Research Backgrounds

Response of biogeochemical cycle to the Arctic sea ice decline has become an important topic for a variety of communities. The improved light condition in summer has enhanced photosynthesis activity of phytoplankton in the Eurasian pelagic area of the Arctic Ocean. A widespread massive deposition of ice algal biomass was detected on the deep seafloor of eastern Arctic basin. In the Beaufort Gyre region of western Arctic, the freshwater accumulation suppressed the primary production of phytoplankton during the 2000s. It is still necessary to further fill many gaps to understand the spatial and temporal variability of biological processes in the Arctic Ocean. In the JAMSTEC field campaign, the year-round bottom-tethered moorings with sediment trap instrument have been deployed in the Northwind Abyssal Plain (NAP) of Chukchi Borderland since October 2010 [1]. At Station NAP (75°N, 162°W, 1,975 m water depth), there was remarkable interannual variability in the summertime particle flux [2]. The trapped particle flux had its sharp peak in August 2011 and was considerably suppressed in summer 2012. The relative abundance of diatom valves suggested the dominance of oligotrophic water originating from the central Canada Basin in 2012. In the present study, we addressed seasonal and interannual variability of ice algae over the Chukchi Borderland using a pan-Arctic ice-ocean modeling approach (Fig. 1).

## 2. Pan-Arctic Coupled Sea Ice-Ocean Model

The physical part of coupled sea ice-ocean model used in the present work is “Center for Climate System Research Ocean Component Model (COCO)” version 4.9. The sea ice component includes a multi-thickness-category configuration and the elastic-viscous-plastic rheology. The ocean component is a free-surface general circulation model formulated with the sophisticated advection scheme and the turbulence closure mixed-layer scheme. The COCO model was coupled with a lower-trophic marine ecosystem model, "North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO)" [3].

In the present work, to address ice algal seasonal and interannual variability, sea ice ecosystem was additionally incorporated (Fig. 2). In the developed model (called as "Arctic NEMURO", hereafter), the habitat of ice algae is confined to the skeletal layer with its thickness of 2 cm. The vertical exchange of biogeochemical variables between the skeletal layer and the ocean surface layer is formulated in the different manner for sea ice freezing and melting periods. We assume that ice algae utilize both ice/ocean nutrients depending on their biomass. The biomass of ice algae is reduced by respiration, mortality, and sea ice melting. In the present experiments, zooplankton grazing on ice algae is neglected. Since the Arctic NEMURO is implemented in three-dimensional frameworks, the horizontal advection of biogeochemical variables in sea ice component is also calculated.

The model domain covers the pan-Arctic region with horizontal resolution of 5 km and 42 vertical levels (Fig. 1). We performed two year-long experiments, where the 5-km grid model was integrated from October 2010 (2011) to September 2011 (2012) in the 2011 (2012) case to examine the seasonal and interannual variability of ice algae. The initial sea ice and ocean physical fields for these experiments were obtained from the decadal experiment from 1979 to 2011 using the 25-km grid version [2]. The atmospheric forcing components

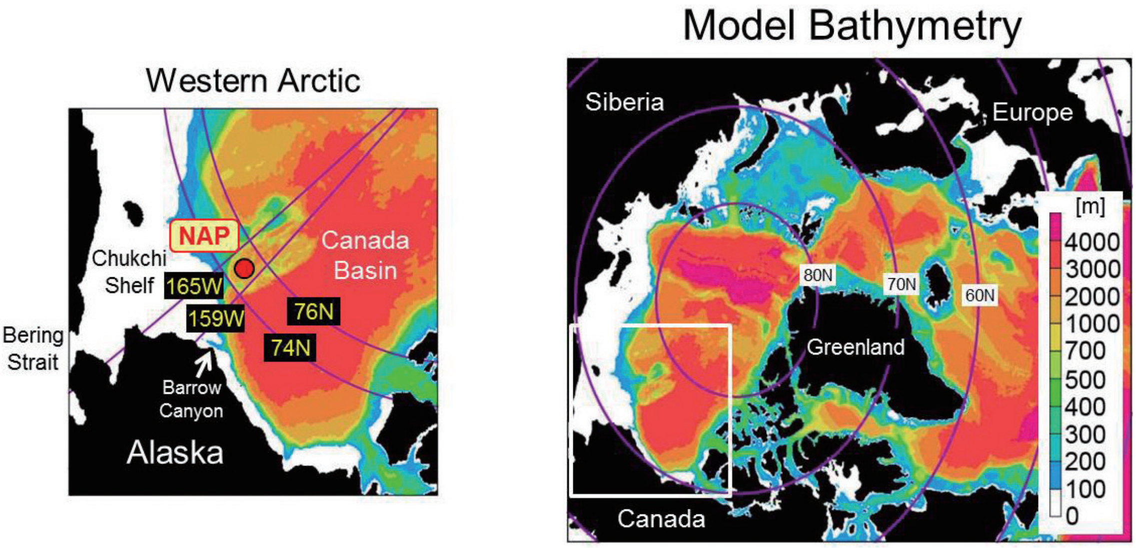


Fig. 1 Model bathymetry [m]. A red dot shows the location of Station NAP, where the JAMSTEC sediment trap has been deployed since October 2010.

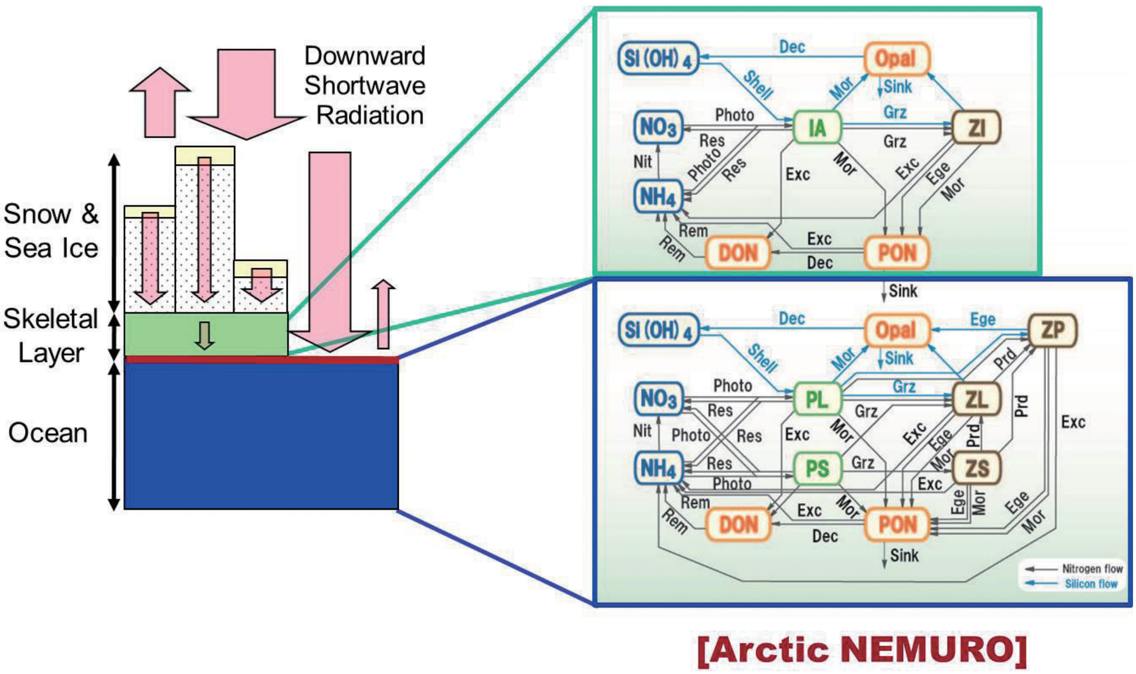


Fig. 2 Schematic image and configuration of the Arctic NEMURO model.

were constructed from the National Centers for Environmental Prediction/Climate Forecast System Reanalysis (NCEP/CFSR) 6-hourly dataset. The summer climatology of nitrate and silicate concentrations derived from the World Ocean Atlas 2013 (WOA13) was assigned to the initial fields of ocean nutrient. In the skeletal layer, sea ice nutrient is initially zero, and the lower limit of ice algal concentration (0.02 mmol-N $m^{-3}$) is given for seeding.

## 3. Seasonal Transition over the Chukchi Borderland

We defined the NAP region enclosed by 74°–76°N and 159°–165°W for following analyses (Fig. 1). In both the 2011 and 2012 cases, the NAP region was entirely covered by sea ice during the winter and spring seasons, and sea ice concentration gradually decreased from May to September. The modeled ice algal bloom started in June and produced the peak biomass at the beginning of August in the 2011 case (Fig. 3a). In the 2012 case, the initial bloom timing was delayed by one month and the ice algal biomass was clearly smaller compared with the 2011 case. The modeled primary production of ice algae demonstrated remarkable spatial and interannual variability in the western Arctic Ocean (Fig. 3b). The shelf-basin contrast of ice algal production was previously detected by the trans-Arctic Ocean expedition operated in the 1990s [4]. In the 2011 case, the local maximum appeared north of the Chukchi and Beaufort shelf breaks. On the other hand, the ice algal productivity was considerably suppressed around the Beaufort Gyre region in the 2012 case. The negative anomaly widely covered the western Arctic except the coastal shelves and the northern part of Chukchi Borderland (Fig. 3c). Station NAP was located near the shelf-basin boundary and also showed the negative anomaly.

The nutrient condition in the sea ice and water columns also showed remarkable interannual variability. The sea ice nitrate content reached the peak value of 0.6 mmol-N $m^{-2}$ (0.2 mmol-N $m^{-2}$) in the 2011 (2012) case. In the beginning period of one-year model integration, the nutricline was located at the depth of 20 m in the NAP region. The early-winter Ekman

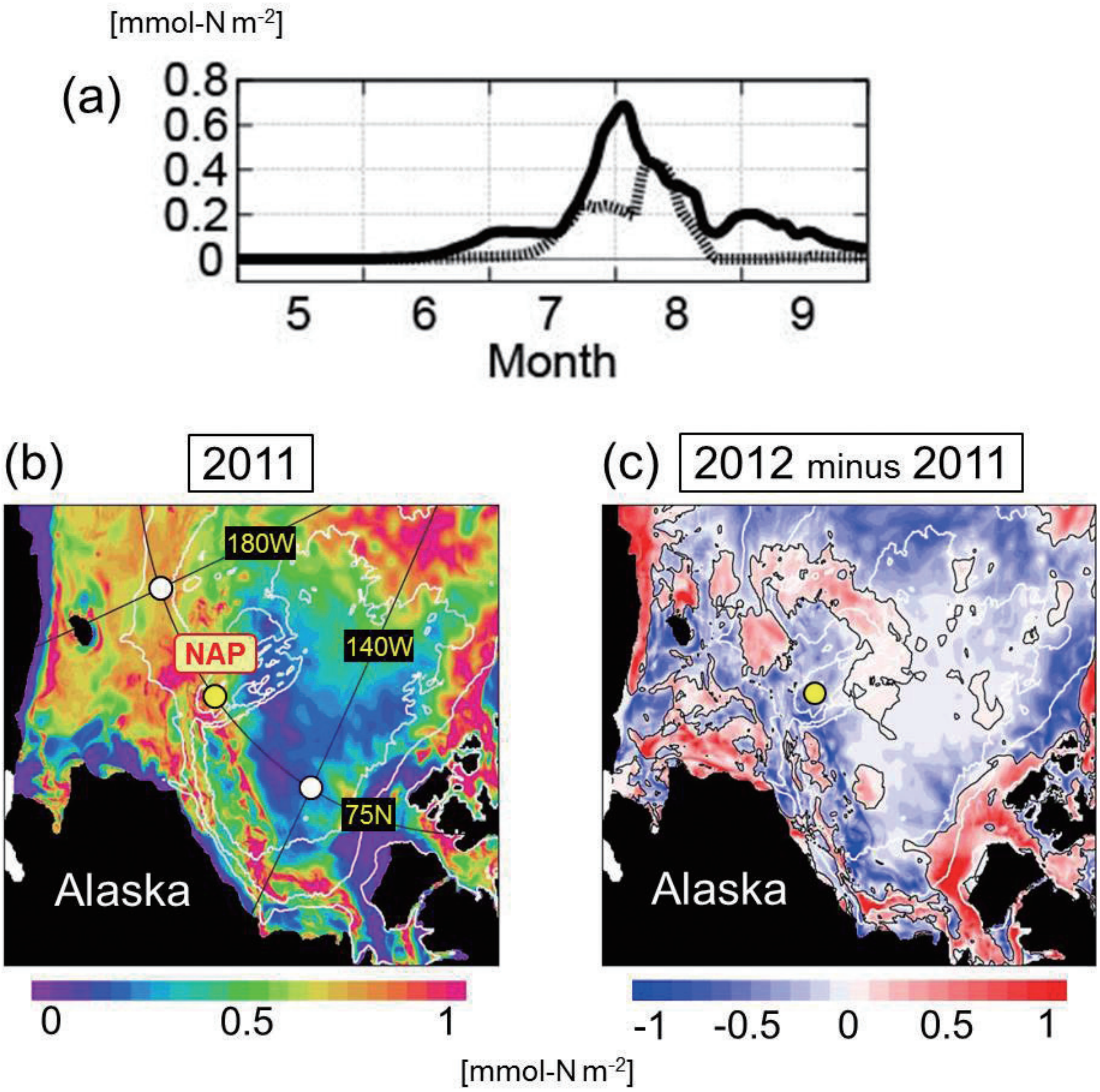


Fig. 3 (a) Modeled seasonal transition of ice algal biomass in the NAP region [mmol-N $m^{-2}$]. A solid (dashed) line corresponds to the 2011 (2012) case. (b-c) Modeled annual primary production of ice algae (b) in the 2011 case and (c) its anomaly in the 2012 cases [mmol-N $m^{-2}$].

downwelling contributed to nutricline deepening in both the cases. More important key process was the occurrence of strong mixing during the winter season in the 2011 case. The resultant surface nitrate concentration increased up to 2 mmol-N $m^{-3}$, and the significant part was imported to the skeletal layer of sea ice bottom. In contrast, the oligotrophic water stayed over the nutricline whose depth was nearly constant or somewhat deepened for the winter time in the 2012 case. Accordingly, the model results suggested that the preconditioning of nutrient accumulation in the sea ice column during the freezing period controlled the initial bloom of ice algae. The nutrient availability for primary production of ice algae certainly reflected the difference in the above-mentioned precondition. The present model formulated that sea ice nutrient was primarily consumed for the initial stage of ice algal bloom and that the matured ice algae could utilize nutrient in the ocean surface layer. The larger growth rate accounted for the earlier initial bloom of ice algae in the 2011 case (Fig. 3a). The sea ice nitrate was rapidly depleted by this initial bloom and partially by the export to water column with sea ice melting. The further bloom utilizing sea water nutrient then occurred in late July.

## 4. Wind Impacts on Ice Algal Variability

To address background mechanisms for the western Arctic ice algal variability on the seasonal to interannual timescales, sea ice and ocean responses to wind forcing were investigated.

We compared the winter mean sea level pressure (SLP) and wind stress fields constructed from the NCEP/CFSR reanalysis data. In the winter season of 2010–2011, anti-cyclonic wind pattern was accompanied by Beaufort High. The easterly wind in the southern Beaufort Sea would have favored the transport of nutrient-rich Chukchi shelf water toward the Canada Basin interior with the NAP region via the Ekman process. On the other hand, in winter 2011–2012, high SLP was extended from Siberian Arctic to the western Arctic Ocean. Accordingly, northwesterly wind prevailed in the Beaufort Sea. It is reasonable that the anomalous wind pattern forced southward transport of oligotrophic water mass within the Beaufort Gyre and eventually lessened nutrient availability over the Chukchi Borderland. The nutrient precondition before the blooming period of ice algae certainly reflected the wind-driven water mass transport. The spatial distribution of ocean nitrate concentration was characterized by the sharp meridional gradient across the Chukchi and Beaufort shelf breaks, as captured by a number of ship-based observations [5]. There was a different tendency of the nitrate content around the NAP region. In the 2011 case, relatively high abundance of nitrate was distributed from the northern shelf of Chukchi Sea to the east of Northwind Ridge along 75°N. On the other hand, the shelf-basin contrast of nitrate content was still apparent even in the southern area of Chukchi Borderland in the 2012 case.

To explore pathways of shelf-break water mass, a virtual passive tracer was provided along the shelf-basin boundary. We chose the tracer source region sandwiched by isobaths of 100 and 200 m. The modeled distribution in March 2011 indicated that the tracer provided along the shelf-basin boundary region was transported from the Chukchi northern shelf toward the Canada basin interior. The tracer northern edge matched the nitrate-rich area in the 2011 case. The model result hence indicated that the Ekman transport of Chukchi shelf water, in addition to the energetic turbulent mixing, enhanced nutrient availability for ice algae in the NAP region. To the contrary, in March 2012, the tracer signal was quite weak over the Chukchi Borderland. The spread of fresher basin water blocked shelf water intrusion and weakened turbulent mixing. The density stratification plausibly controlled ocean surface mixing since wind speed was comparable on the averages from November to January of the 2011 and 2012 seasons. The modeled nitrate distribution and tracer pathway supported that the transport of oligotrophic water from the Canada Basin interior toward the NAP region would be an important factor for the suppressed primary productivity of ice algae in summer 2012.

## Acknowledgement

This work was funded by the Grants-in-Aid for Scientific Research of Japan Society for the Promotion of Science (No. 22221003 and No. 26800428) and GRENE Arctic Climate Change Research Project. The authors appreciate continuous support from the Center for Earth Information Science and Technology (CEIST) of JAMSTEC.

## References

[1] Watanabe, E., et al., Enhanced role of eddies in the Arctic marine biological pump, *Nature Comm*., 5, 3950 doi:10.1038/ncomms4950 (2014).

[2] Onodera, J., E. Watanabe, N. Harada, and M. C. Honda, Diatom flux reflects water-mass conditions on the southern Northwind Abyssal Plain, Arctic Ocean, *Biogeosciences*, 12, 1373–1385, doi:10.5194/bg-12-1373-2015 (2015).

[3] Kishi et al., NEMURO–a lower trophic level model for the North Pacific marine ecosystem, *Ecol. Model*., 202, 12–25 (2007).

[4] Gosselin, M., M. Levasseur, P. A. Wheeler, R. A. Horner, and B. C. Booth, New measurements of phytoplankton and ice algal production in the Arctic Ocean, *Deep Sea Res.-II*, 44, 1623–1644 (1997).

[5] Nishino, S., T. Kikuchi, M. Yamamoto-Kawai, Y. Kawaguchi, T. Hirawake, and M. Itoh, Enhancement/reduction of biological pump depends on ocean circulation in the sea-ice reduction regions of the Arctic Ocean, *J. Oceanogr*., 67, 305–314 (2011).

# 地球環境変化に伴う生態系変動の診断と予測に関する研究

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北極海における近年の急激な海氷減少は大気・海洋場への影響も含めて社会的関心事の１つとなっている。ベーリング海峡から流入する太平洋起源水は北極海の熱・淡水・栄養塩の主要な供給源であり、その輸送は西部北極海の海氷変動や海洋生態系と密接な関係にある。海洋研究開発機構では、太平洋側北極海のノースウィンド深海平原（NAP）にセディメントトラップ係留系を設置し、2010 年 10 月から現在に至るまで沈降粒子の時系列観測を実施している。セディメントトラップによる現場観測は北極海でもこれまでにカナダ側のマッケンジー陸棚縁やロシア側のラプテフ海北部で行われてきたが、太平洋起源水の下流域にあたる NAP 周辺で複数年に渡って実施されたのは今回が初めてである。その時系列観測結果からは、2011 年夏季に海氷種（アイスアルジー）を多く含む沈降粒子量極大が捉えられている一方で、翌年の 2012 年夏季には沈降粒子量が著しく少ないことが報告されている。北極海全域を対象とする 5 km 格子の海氷海洋結合モデルで季節変動実験を実施し、ノースウィンド深海平原での基礎生産性および粒子沈降に関して解析を行った。本研究では、新たに海氷生態系を含む Arctic NEMURO モデルを開発し、北極海全域を対象にした海氷海洋物理モデル COCO に結合させることで、現実的なアイスアルジーの季節変化を表現することができた。またセディメントトラップによる時系列観測結果が得られている 2011 年と 2012 年の比較から、NAP 地点でのアイスアルジー成長は冬季風系場にも強く依存し、貧栄養なカナダ海盆水が拡がるような状況では基礎生産性が著しく低下するという結果が得られた。今後は 2014 年 9 月にカナダ砕氷船アムンゼン号で回収された３つの係留系観測結果とも照らし合わせて、引き続き時空間変動の解析を行う予定である。

キーワード: 北極海, ノースウィンド深海平原, アイスアルジーモデル, 基礎生産, 風系場