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

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We involve two big projects, and will describe separately. First project is on Arctic Ocean and second one is on ecosystem model comparison program.

The impact of sea ice decline on biological regime associated with Pacific water transport in the western Arctic basin is examined using a pan-Arctic eddy-resolving coupled sea ice-ocean model including a lower-trophic marine ecosystem formulation. The model results suggested that local primary production and following food chain can explain a summertime peak of sinking mass flux observed by sediment trap measurements at the Northwind Abyssal Plain that were deployed by JAMSTEC. On the other hand, another maximum during winter would be caused by advection processes via combination of warm shelf-break eddies and the anti-cyclonic Beaufort Gyre.

Vertical profile of diatom in global oceans is associated with nutrient distributions affected by physical characteristics and dynamics of seawater, and links to efficiency of biological pump down to deep oceans. Here we compared the vertical profile of diatoms derived from the state-of-the-art global marine ecosystem models to see how it changes over the coming century. Numerical simulations using the Earth Simulator show that the present-day vertical profile may change in the future except high latitudes, so that a diatom-specific chlorophyll maximum layer will be found at a greater depth by the end of the 21st century.

Keywords: pan-Arctic ice-ocean model, shelf-basin exchange, warm eddies, Marine Ecosystem Model Intercomparison Project, vertical profile, diatoms

1. Process modeling on Arctic marine ecosystem

A pan-Arctic ice-ocean model was redesigned to address the western Arctic basin ecosystem in the viewpoint of Pacific water transport with heat and biogeochemical materials. The physical part of model is CCSR Ocean Component Model (COCO) version 4.9. The model domain is composed of the entire Arctic Ocean and the northern North Atlantic. In this study, two experimental designs with different horizontal resolution were set up. First, a decadal experiment from 1979 to recent years was conducted using a 25-km grid version. The seasonal run with an eddy-resolving version (grid size of 5-km) was then integrated from the results of decadal experiment. The atmospheric forcing components were constructed from the NCEP/NCAR reanalysis daily data. The COCO model demonstrated realistic performances of physical fields, such as sea ice volume in the entire Arctic, sea ice export through the Fram Strait, major branches of northward current in the Chukchi shelf, and Beaufort shelf-break eddies. To address biological responses to these physical backgrounds, a lower-trophic marine ecosystem model NEMURO was coupled to the COCO (Fig. 1), as same as our previous work [1]. Since dissolution from sea bottom sediments is an important nutrient source in the Chukchi shelf, nitrogen and silicate fluxes from shelf bottom were also considered. As a first step, quasi-uniform nutrient distribution in bottom sediments was assumed accounting for bio-turbation. In addition, to visualize the transport of shelf bottom water, a virtual passive tracer was provided in the deepest layers just above the entire sea bottom. The model results suggested that local primary production and following food chain can explain a summertime peak of sinking mass flux observed in the Northwind Abyssal Plain (NAP). On the other hand, another maximum during winter would be caused by advection processes via combination of warm shelf-break eddies and the anti-cyclonic Beaufort Gyre.

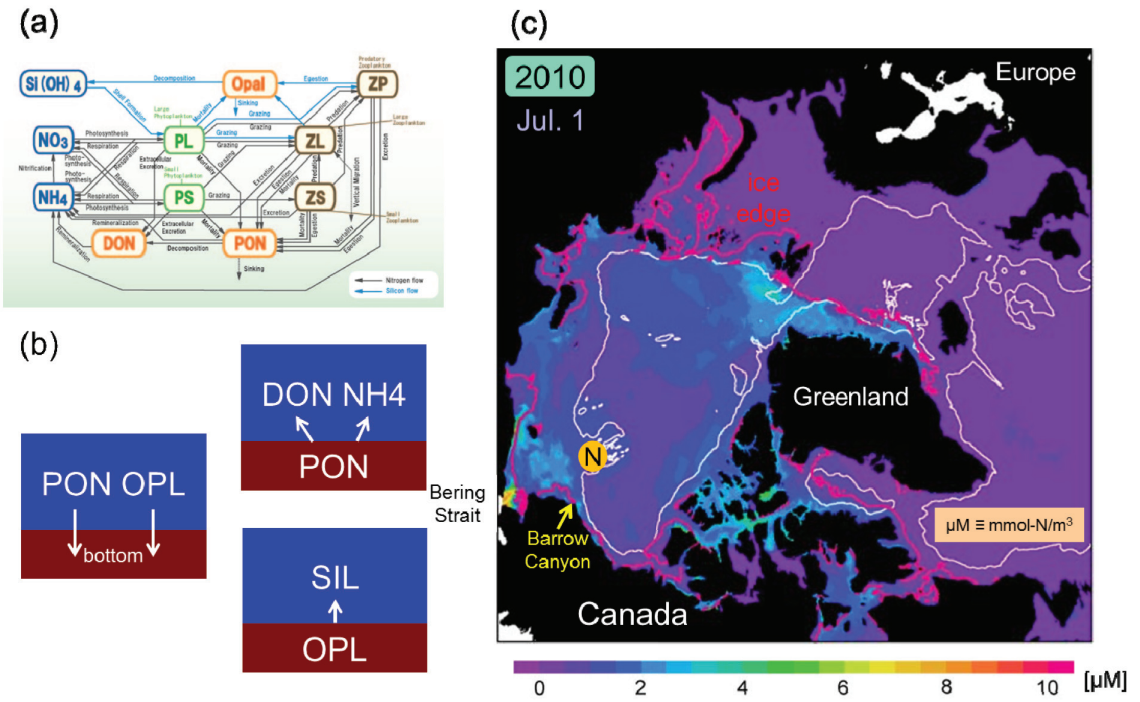


Fig. 1 (a) NEMURO configuration. (b) Image of modeled bottom processes. (c) Modeled surface phytoplankton concentration on July 1 in the 2010 case [mmol-N/m^3]. White contours show 1000m isobaths. Pink contours show modeled sea ice edge. Station NAP is located at label "N".

2. Modeling the present-day and the future vertical structure of diatoms

The COCO-MEM is a Marine Ecosystem Model (MEM, Shigemitsu et al., 2012) developed by Hokkaido University and JAMSTEC that explicitly represents phytoplankton functional types such as diatoms. The MEM can be coupled with the 3D general circulation model, COCO version 3.4, with 1×1 degree spatial resolution for global oceans. Historical (1985-2007) and future (2010-2100) experiments were conducted in this this study to model a vertical structure of diatoms. NCEP/NCAR re-analysis data were used for the atmospheric forcing in the historical runs, whereas outputs from the earth system model MIROC using RCP8.5 scenario were used in the future runs. Vertical structure of diatoms derived from the MEM was compared to other marine ecosystem models under the international project, MARine Ecosystem Model Intercomparison Project (MAREMIP). Figures 2 shows an average pigment biomass of diatoms at the surface for the decade of 1997-2006 and 2091-2100 derived from several MAREMP models; ESM2M by Geophysical Fluid Dynamics Laboratory (GFDL, USA), COCO-MEM by Hokkaido University/Japan Agency for Marine-Earth Science and Technology (HU/JAMSTEC, Japan), MRI.COM by Meteorological Research Institute (MRI, Japan), NASA Ocean Biogeochemical Model by National Aeronautics and Administration (NASA, USA), BEC by Woods Hole Oceanographic Institution (WHOI, USA).

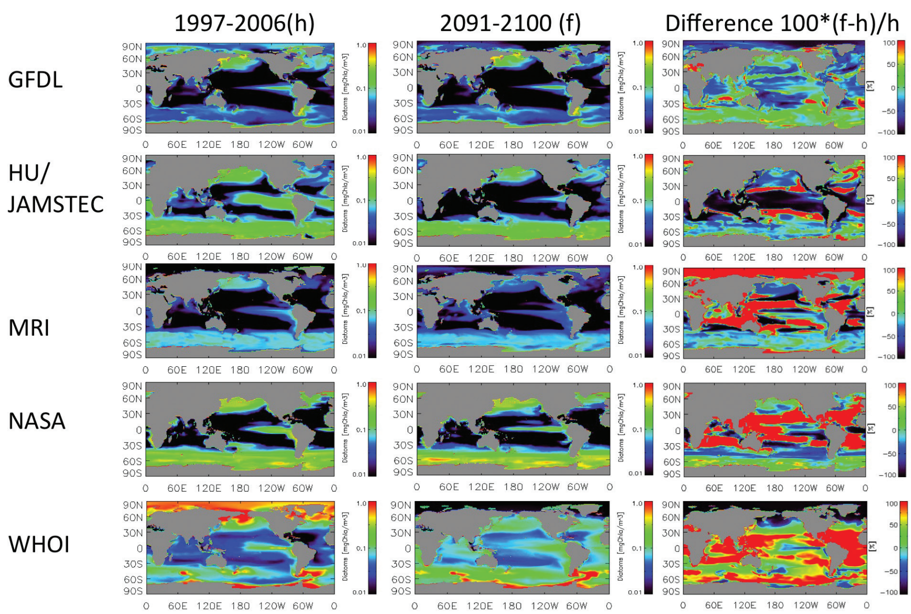


Fig. 2 Surface distributions of diatoms derived from MAREMIP models.

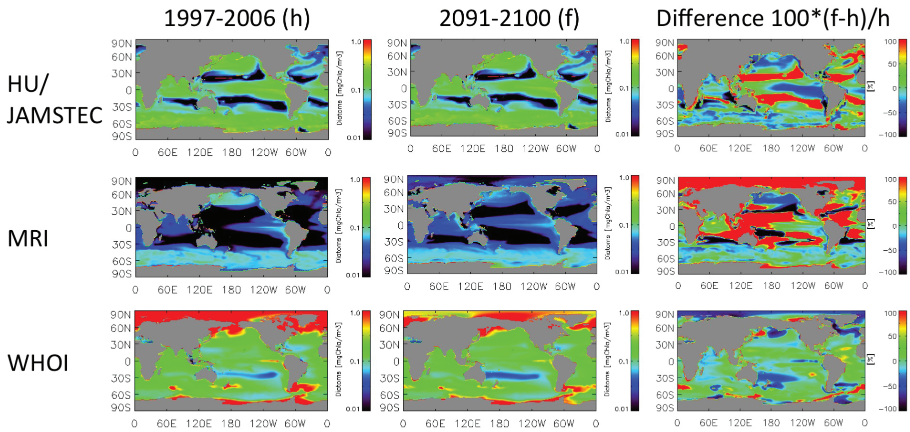
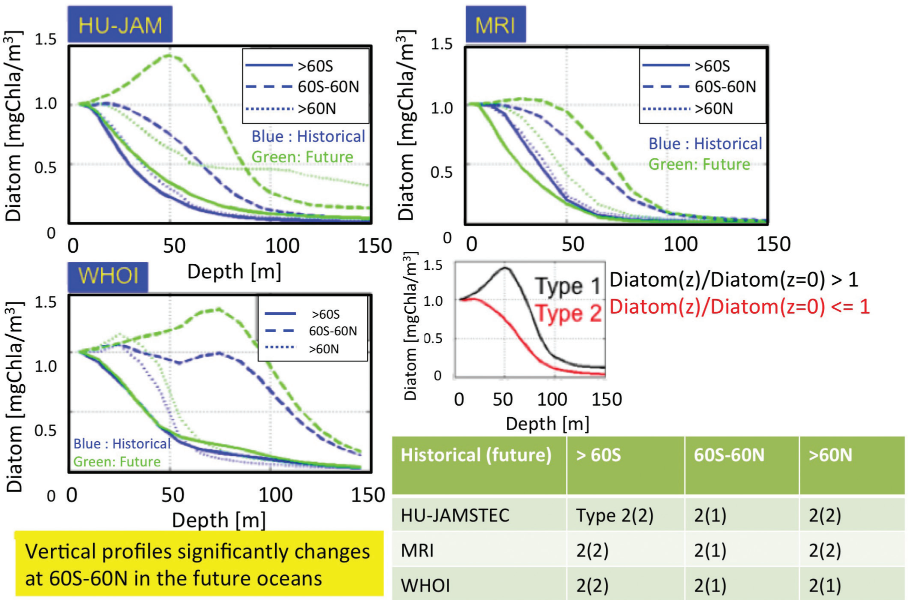


Fig. 3 Global distribution of pigment biomass at a depth where the biomass reaches its maximum, for three models selected from MAREMIP models.



Historical (future)	> 60S	60S-60N	>60N
HU-JAMSTEC	Type 2(2)	2(1)	2(2)
MRI	2(2)	2(1)	2(2)
WHOI	2(2)	2(1)	2(1)

Fig. 4 Vertical profiles of pigment biomass of diatoms averaged over different latitudinal zones (>60°N, 60°N to 60°S, >60°S).

All models analyzed here predict a decrease of diatoms at the surface in equatorial waters, whereas an increase in sub-tropical waters. However, pigment biomass of the diatoms remains very low both in the present-day and the future. Similar tendencies were found for the pigment biomass at a depth where the biomass reaches its maximum in the vertical profile as depicted in Fig. 3 (therefore not all models shown), except in the Arctic oceans by WHOI model where a significant decrease.

Figure 4 show vertical profiles of pigment biomass of diatoms averaged over different latitudinal zones (>60°N, 60°N to 60°S, >60°S). The vertical profile may be classified into two types, one showing a subsurface maximum of the pigment biomass (defined as Type 1), and the other showing a monotonic decrease of the pigment biomass with depth (Type 2). It was found from the MAREMIP models that the vertical profile type changes from Type 2 in the present-day oceans to Type 1 in the future oceans in most of the oceans (i.e. 60°N to 60°S) except at higher latitudes, or more diatoms is found in a relatively greater depth in the future for these waters, thus implying a potential of habitat sift of the diatoms vertically.

Acknowledgements

The numerical experiments conducted by the Earth Simulator enabled the comparison of COCO-MEM to other models under MAREMIP framework. The authors appreciate continuous support from the Earth Simulator Center. All model output providers who contributed to MAREMIP are also appreciated.

Reference

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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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この課題には大きく２つのプロジェクトが含まれている。一つは北極の生態系を解明するもので、もう一つは生態系モデル国際比較プロジェクトである。以下、その成果の要旨を順に記す。

沿岸流・渦活動・湧昇などの背景物理場が低次生態系に果たす役割を明らかにするために、北極海全域を対象とした水平 5km 格子の高解像度大循環モデルを整備し、陸棚海底起源の栄養塩の海盆域への拡がり等を議論できる体制を整えた。それに関連して、西部北極海に多く存在する中規模渦が基礎生産に及ぼす役割について論文や複数の学会で報告した。また（独）海洋研究開発機構がノースウィンド深海平原に係留しているセディメントトラップで得られた生物由来物質の時系列変化に対して、サブ海盆スケールの水塊輸送の重要性を示唆した。他国で運用されている３次元生態系モデルの殆どは背景物理場の水平解像度が数十 km と粗く、海盆スケールの循環場でさえ再現性が十分とは言えない。その点、本研究で用いる物理生態系結合モデルは世界最高レベルの解像度で実装されており、渦から大循環に至るまで幅広い空間スケールで物理場と生態系の関係を議論することができ、ブレイクスルーが期待される。

海洋の珪藻類の鉛直分布は、生物による深層への炭素の輸送（生物ポンプ）の効率と関連しており、栄養塩分布や海水の物理特性や力学により影響を受ける。この研究では、珪藻類の鉛直分布が将来どのように変化するかを、最新の生態系モデルのシミュレーション結果を比較することにより考察した。地球シミュレーターを用いた数値実験の結果は、現在における珪藻類の鉛直分布が北緯六十度から南緯六十度における海域で変化し、珪藻の鉛直極大層が二十一世紀末までにより深い深度に移行する可能性が示唆された。

キーワード : 北極海物理生態系結合モデル , 陸棚海盆間輸送 , 暖水渦 , 海洋生態系相互比較プロジェクト , 珪藻 , 鉛直分布