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

Project Representative

Michio J. Kishi   Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology

Authors

Akio Ishida[*1, 2], Yoshikazu Sasai[*1], Maki Noguchi Aita[*1], Eiji Watanabe[*1], Taketo Hashioka[*3], Takafumi Hirata[*3] and Yasuhiro Yamanaka[*1, 3]

*1 Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology

*2 Department of Social Environment, Fuji Tokoha University

*3 Faculty of Environmental Earth Science, Hokkaido University

In this project we will improve the ability to simulate the present status of ocean climate and ecosystems and clarify effects of climate variability on marine biogeochemical cycles and ecosystems by using multiple ocean general circulation models (GCMs) with multiple ecosystem models including marine biogeochemical cycles. We have investigated the impact of climate variability on the marine ecosystem in the northeastern tropical Pacific using our high-resolution model. We also have examined the mechanisms of phytoplankton competition during the spring bloom in the first phase of Marine Ecosystem Model Intercomparison Project (MAREMIP). We also work on the development of Arctic marine ecosystem model to investigate the impact of sea ice and ocean dynamics on the polar ecosystem.

Keywords: Ecosystem, Biogeochemical Cycles, Global Change, Ocean General Circulation Model, Fisheries resources

1. High resolution modeling of biogeochemical cycles and ecosystems

Using an eddy-resolving OGCM (OFES) coupled with a simple ecosystem (NPZD) model, we have investigated the seasonal and interannual variabilities of the chlorophyll in the northeastern tropical Pacific during 2000-2007. The seasonal variability of the surface chlorophyll concentration in the model agrees well with satellite ocean color data, except for the equatorial region [1]. High chlorophyll levels off the Gulf of Tehuantepec, Papagayo, and Panama in winter and in the Costa Rica Dome in summer are well reproduced. Production in these areas is controlled by the supply of nitrate rich-waters through vertical mixing and coastal and open ocean upwelling. The variability of the thermocline depth is strongly connected to the seasonal variability of surface chlorophyll. El Niño Southern Ocean (ENSO) variability has a marked effect on the marine ecosystem in this region. The model reproduces the chlorophyll variability corresponding to the observed ENSO variability.

2. Process modeling in marine ecosystems

In the first phase of Marine Ecosystem Model Intercomparison Project (MAREMIP), we investigated the mechanisms of phytoplankton competition during the spring bloom, one of the most dramatic seasonal events in lower-trophic level ecosystems, in four Plankton Functional Types (PFTs) models: NEMURO (JAMSTEC, Hokkaido Univ.), PISCES (IPSL, France), PlankTOM5 (UEA, UK) and CCSM-BEC (WHOI, US). As a common feature of all investigated models, the percentage of diatoms with respect to total phytoplankton increases with the magnitude of the spring bloom (Fig. 1). However, the mechanisms governing succession differ among models, despite the fact that current PFT models parameterize the same types of ecophysiological processes. The differences in the mechanisms suggest that the response of marine ecosystems to climate change could significantly differ among models. Through this first model intercomparison of the PFTs models, several key processes for further understanding

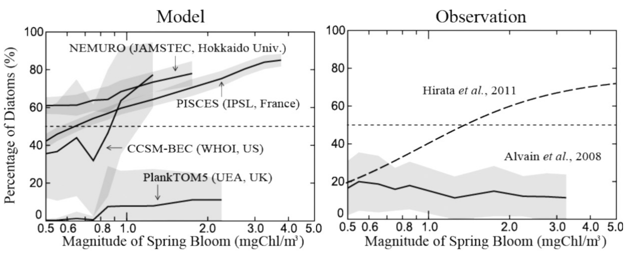

Fig. 1. Percentage of diatoms (large group) with respect to total phytoplankton at the peak timing of the bloom as a function of the bloom magnitude in the North Pacific (right: model results, left: observation). The shades are the spatial standard deviation in the blooming region of each model and satellite estimations.

have been made clear.

In order to assess model performance on spatial distributions of PFTs, spatial patterns of PFTs derived from models were compared to these derived from satellite observation [2, 3]. The model skill score for the advanced version of NEMURO (i.e. Marine Ecosystem Model with Optimal Nutrient Uptake Kinetics, MEM) are shown in Fig. 2 as functions of PFTs pigment biomass (i.e. fractional Chlorophyll-a of PFTs) and spatial scales of their patterns [4]. We found that the model successfully reproduces spatial patterns derived from satellite observation at the spatial scale > 1800 km^2. Even at smaller spatial scales (<200km^2), spatial patterns in the model tends to agree with those in the satellite, when the pigment biomass is either small or large (but not "intermediate"). This tendency is also found in another model such as the European Regional Sea Ecosystem Model, ERSEM (not shown). Thus, the state-of-the-art models are successful in reproducing spatial patterns when a spatial contrast in pigment biomass is large enough.

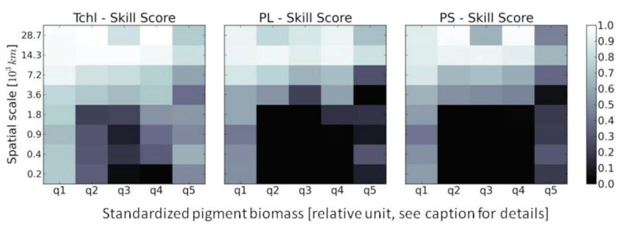

Fig. 2. Model skill score derived from wavelet analysis as functions of the spatial scale (y) and pigment-biomass (x) for Total phytoplankton community (Tchl), Diatoms (PL) and other small-sized phytoplankton (PS). Colour tone shows the skill score (0 to 1), brighter being better and darker being poorer. q1, q2…q5 show quantiles (20%, 40%, …, 100%) in pigment biomass data distribution.

3. Process modeling on Arctic marine ecosystem

Response of primary productivity to the Beaufort shelf-break eddies is examined following eddy life stages using an eddy-resolving sea ice-ocean model with a lower-trophic marine ecosystem formulation [5]. During late summer and early autumn, the shelf-break warm eddies initially transport the Chukchi shelf water with high primary productivity toward the southern Canada Basin (Fig. 3). In the eddy-developing period, the anti-cyclonic rotational flow along the outer edge of each eddy occasionally traps the shelf water. In the eddy-maturity period, the primary production inside the warm eddies is maintained by eddy dynamics, partly attributing to turbulent vertical mixing with underlying nutrient-rich water. In the eddy-decay period, light limitation before sea ice freezing shuts down the primary productivity in spite of nutrient recovery. These modeling analyses indicate that the time lag between phytoplankton bloom following summertime sea ice retreat in the Chukchi shelf region and eddy generation north of the Barrow Canyon is an important index to determine biological regimes in the western Arctic basin. Interannual variations in eddy performances would have a significant impact on the bottom-up control of food chains.

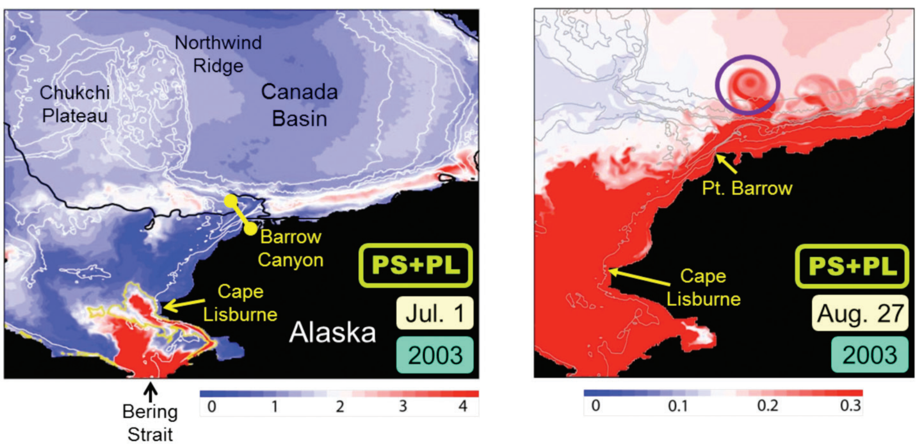

Fig. 3. Surface phytoplankton concentration on (left) July 1 and (right) August 27 in the 2003 case demonstrated by the coupled sea ice-ocean model with a lower-trophic marine ecosystem formulation [mmolN/m^3]. White contours show bottom bathymetry. Black contours in the left figure correspond to the simulated sea ice concentration of 0.5.

References

[1] Y. Sasai, K. J. Richards, A. Ishida, and H. Sasaki, Spatial and temporal variabilities of the chlorophyll distributions in the northeastern tropical Pacific: The impact of physical processes on seasonal and interannual time scales, *J. Marine Systems*, 96-97, 24-31. DOI:10.1016/j.jmarsys.2012.01.014, 2012.

[2] T. Hirata, N. J. Hardman-Mountford, R. J. W. Brewin, J. Aiken, R. Barlow, K. Suzuki, T. Isada, E. Howell, T. Hashioka, N. Aita-Noguchi, and Y. Yamanaka, Synoptic relationships between surface Chlorophyll-a and diagnostic pigments specific to phytoplankton functional types, *Biogeosciences*, 8, 311-327, 2011.

[3] S. Alvain , C. Moulin, Y. Dandonneau, and F. M., Breon, Remote Sensing of phytoplankton groups in case 1 waters from global SeaWiFS imagery, *Deep-Sea Research Part I*, 52, 1989-2004, 2005.

[4] M. Shigemitsu, T. Okunishi, J. Nishioka, J., H. Sumata, T. Hashioka, M. Aita-Noguchi, S. L. Smith, N. Yoshie, N. Okada, and Y. Yamanaka, Development of one-dimensional ecosystem model including the iron cycle applied to the Oyashio region, western subarctic, *Journal of Geophysical Research – Oceans*, (*submitted*).

[5] E. Watanabe, M. J. Kishi, A. Ishida, and M. N. Aita, Western Arctic primary productivity regulated by shelf-break warm eddies, *Journal of Oceanography*, 2012, (in revision).

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

プロジェクト責任者

岸　　道郎　　海洋研究開発機構　地球環境変動領域

著者

石田　明生 *[1,2]，笹井　義一 *[1]，相田（野口）真希 *[1]，渡邉　英嗣 *[1]，橋岡　豪人 *[3]，平田　貴文 *[3]，山中　康裕 *[1,3]

*1　海洋研究開発機構　地球環境変動領域

*2　富士常葉大学　社会環境学部

*3　北海道大学　大学院地球環境科学研究院

本プロジェクトでは、空間解像度や複雑さの異なる複数の海洋生態系モデル、海洋大循環モデルを用いて、現在の気候条件における生態系変動再現実験、及び、温暖化気候における将来予測実験を通して、生態系の変動特性の定量化、生態系の将来予測、海域による海洋生態系の違いや卓越種の再現を目指した生態系モデル開発を実施する。今年度は、高解像度海洋大循環・海洋生態系結合モデルを用いて東部赤道太平洋における気候変動が表層のプランクトン分布に与える影響について議論した。また、MAREMIP（MARine Ecosystem Model Intercomparison Project）において、異なる生態系プロセスモデル結果の相互比較、観測データとの比較を通じた植物プランクトンの種間競争メカニズムの解析を行った。さらに、西部北極海を対象とした渦解像海氷海洋物理モデルに低次海洋生態系モデル（NEMURO）を結合し，植物プランクトンの主要な時空間変動特性の再現に成功した。その結果、チャクチ陸棚域での植物プラントンブルームと陸棚海盆境界域での暖水渦生成のタイムラグが渦内部の生物化学的特性および基礎生産性を大きく支配することが明らかになった。

キーワード:生態系, 物質循環, 気候変動, 高解像度海洋大循環モデル, 水産資源