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

Project Representative

Eitaro Wada Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology

Authors

Yasuhiro Yamanaka [*1, 2], Akio Ishida [*1], Yoshikazu Sasai [*1],
Maki Noguchi Aita [*1] and Yoshio Masuda [*2]

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

*2 Faculty of Environmental Earth Science, Hokkaido University

Using multiple ocean general circulation models (GCMs) with multiple ecosystem models including marine biogeochemical cycles, we will improve the ability to simulate the present status of ocean climate and ecosystems and clarify effects of climate change on marine biogeochemical cycles and ecosystems. Especially, our aims are future projections of the impact of climate change on marine ecosystems and oceanic uptake of anthropogenic carbon dioxide. We will also produce data sets to be used for future projection of fisheries resources in both coastal and pelagic oceans.

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

1. Results of high resolution biogeochemical cycles and ecosystem models

We have published results using a super high resolution model, the Ocean general circulation model For the Earth Simulator (OFES) including a simple ecosystem model (Nutrient-Phytoplankton-Zooplankton-Detritus, or NPZD type), with a horizontal resolution of 0.1 degrees [3, 4], cooperating with researchers in the project "Understanding and Forecasting High-Impact Phenomena in the Atmosphere and Ocean" (project representative: Wataru Ohfuchi). We also have published studies on the impact of ocean carbon sequestration and redistribution of injected CO_2 using the physical field of the OFES model [1, 5].

Using the high resolution model forced by high resolution satellite wind fields, we have successfully simulated the seasonal variability of surface chlorophyll influenced by the meso-scale eddies and upwelling associated with the strong offshore wind jets in the eastern tropical Pacific (Fig. 1). In March, upwelling generated by the wind jets in the Gulfs of Tehuantepec, Papagayo, and Panama brings up cold and nitrate-rich waters from subsurface layer, where the tropical spring bloom occurs and is transported offshore. The Costa Rica Dome develops with wind fields west of the Gulf of Papagayo and it supports high chlorophyll by the nutrient supply with upwelling [3].

2. Eddy-resolving and none-eddy modeling for chemical tracer simulation

To investigate the dependence of the simulated results on the model spatial resolution, we have performed numerical experiments with models of different horizontal resolution (0.1 and 0.5 degrees) for chlorofluorocarbon (CFC-11), which is an ideal tracer for evaluating models because it is inert biologically and of purely anthropogenic origin. The global inventories from the models 4.90×10^8 moles (0.5 degrees model) and 5.10×10^8 moles (0.1 degrees model) are nearly the same as the observed data 5.44×10^8 moles. The distribution is also well simulated in the models: high inventory in the Southern Ocean and in the North Atlantic Ocean where deep and bottom waters are formed (Fig. 2). Although the models and observed data generally agree well, their detailed structures are different: The high inventory between 60°S and 30°S captured in the eddy-resolving model is much better as compared with coarse resolution model, however, the high inventory in the northwestern North Atlantic and in the Labrador Sea is better in the 0.5 degrees model than in the 0.1 degrees model.

3. Interannual-decadal variability of carbon cycle simulated with the 3-D NEMURO model

Using a 3-D ecosystem model (COCO-NEMURO), which consists of the CCSR Ocean Component Model (COCO, developed by the Center for Climate System Research

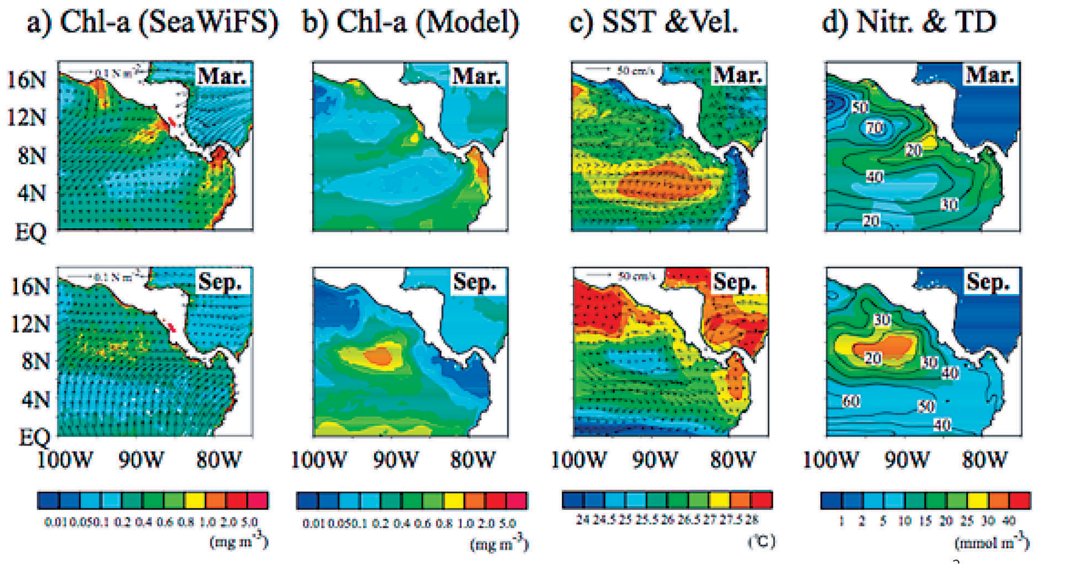

Fig. 1 Distribution of monthly climatological mean surface chlorophyll concentration (mg m^{-3}) from (a) SeaWiFS with QSCAT wind stress (vectors in N m^{-2}), (b) model, (c) simulated sea surface temperature (°C) and horizontal velocity at 25 m depth (vectors in cm s^{-1}), and (d) mean nitrate concentration (mmol N m^{-3}) upper 75 m depth and thermocline depth (contours in m, 20°C isotherm depth).

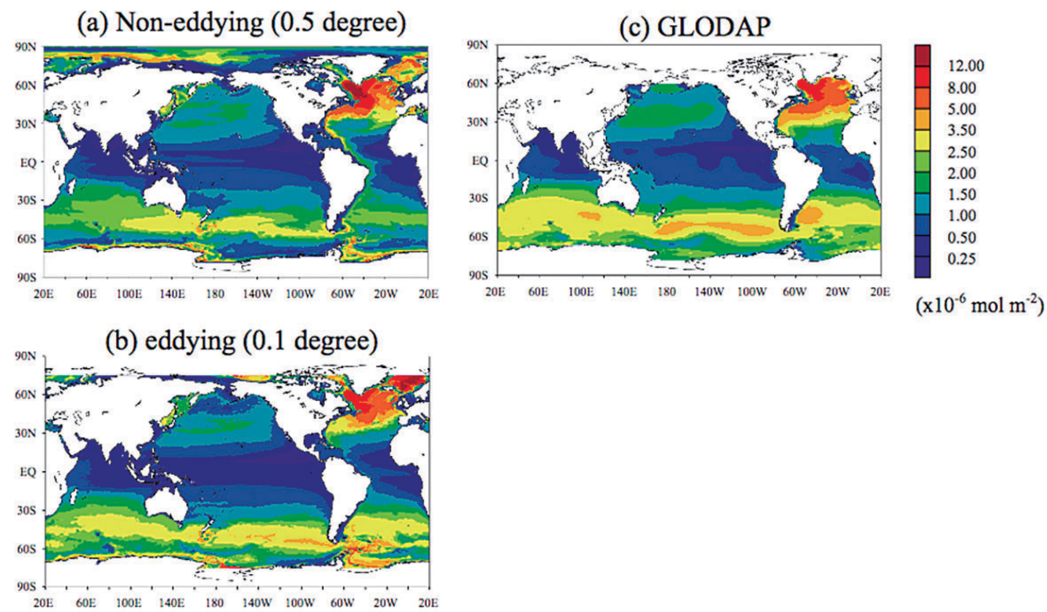

Fig. 2 Horizontal distribution of CFC-11 inventory from the model with 0.5 degrees resolution (a), 0.1 degrees (b), and the data-based estimation (c).

(CCSR), University of Tokyo) coupled with the North pacific Ecosystem Model Used for Regional Oceanography (NEMURO), we have conducted a historical experiment from 1760 to 2002 [2, 9]. The data is used for future projection of fisheries resources in both coastal and pelagic oceans [6–8, 10]. In this experiment, we also simulated the carbon cycle with two boundary conditions for atmospheric pCO_2: one using the historical increase in atmospheric pCO_2 from pre-industry (historical run), another with a constant pre-anthropogenic concentration of 278 ppmv (control run) in order to quantify the anthropogenic carbon cycle. The modeled surface ocean at the Hawaiian Ocean Time-series (HOT) shows a long tern shift in carbonate equilibrium to lower pH and lower saturation states of the carbonate mineral aragonite, which are consistent with the observations. The model also simulates the Pacific Decadal Oscillation (PDO), which is a dominant climate variation in the North Pacific (Fig. 3). Associated with surface temperature decrease after the climate shift during the mid 1970s, primary production increases and CO_2 flux decreases in decadal time scale with interannual variability. We will continue to analyze more detailed results to understand the relationships between cli-

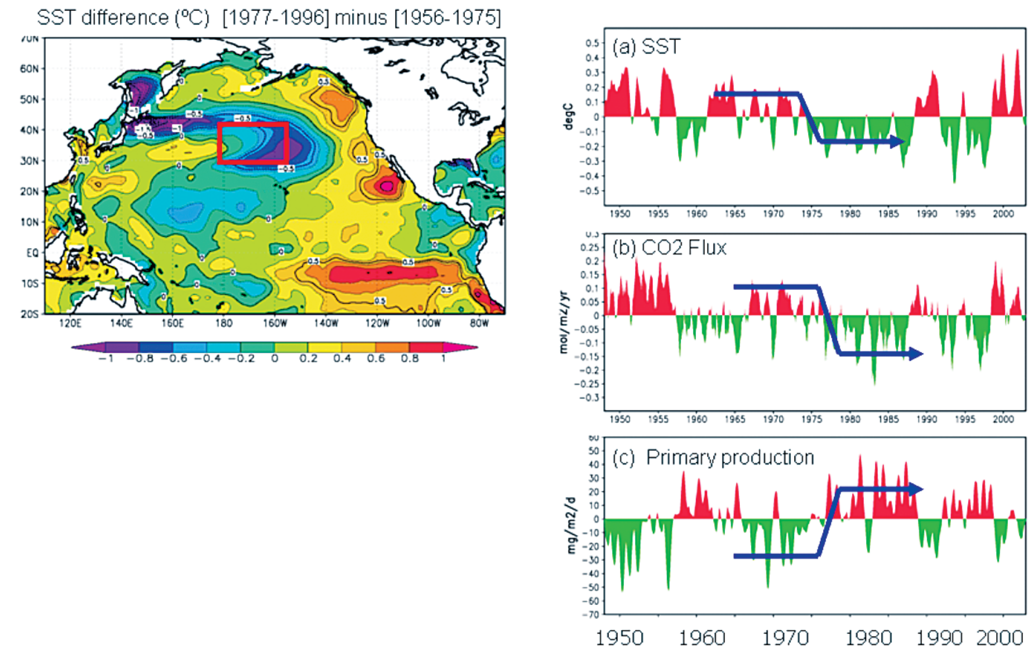

Fig. 3 Simulated sea surface temperature anomaly difference between the averages during 1977–1996 and 1956–1975 (left panel). The right panels show the time-series of anomalous surface temperature (a), CO_2 flux (b), and primary production (c) averaged in the red box in the left panel.

mate change and oceanic uptake and also between the natural and anthropogenic carbon cycle.

4. Effects of iron on phytoplankton distribution using a global 3-D ecosystem model (NEMURO)

In some areas of the oceans with high levels of nutrients, phytoplankton do not grow as much as expected based on nutrient concentrations. It is hypothesized that the lack of iron is a limiting factor for growth of phytoplankton. In fact, the present version of the global 3-D NEMURO model has a bias in that the modeled primary production is higher than the observations in the Southern Ocean and in the eastern equatorial Pacific Ocean, both of which are known as HNLC (High Nutrient, Low Chlorophyll) regions. To improve the model, we developed an iron cycle model, which is combined with the NEMURO model. Preliminary results with this new model show a significant improvement: chlorophyll in the Southern Ocean and eastern equatorial Pacific Ocean is lower by about 50 % compared to the previous model (Fig. 4). We plan to conduct a hind-cast run using this NEMURO model including the iron cycle.

References

[1] Y. Masuda, Y. Yamanaka, Y. Sasai, M. Magi, T. Ohsumi: Site selection in CO_2 ocean sequestration: dependence of CO_2 injection flux on eddy activity distribution. International J. Greenhouse Gas Control, (accepted).

[2] M. N. Aita, K. Tadokoro, Y. Yamanaka, M. J. Kishi: Interdecadal variability of the lower trophic ecosystem in the subarctic seas of the North Pacific in a 3-D implementation of the NEMURO model. Fish. Oceanogr., (submitted).

[3] Y. Sasai, H. Sasaki, K. Sasaoka, A. Ishida, Y. Yamanaka: Marine ecosystem simulation in the eastern tropical Pacific with a global eddy resolving coupled physical-biological model. Geophys. Res. Lett., 34, L23601, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[4] Y. Sasai, K. Sasaoka, H. Sasaki, and A. Ishida: Seasonal and Intra-Seasonal Variability of Chlorophyll-a in the North Pacific: Model and Satellite data. J. Earth Simulator, 8, 3–11, 2007.

[5] Y. Masuda, Y. Yamanaka, Y. Sasai, M. Magi, T. Ohsumi: A numerical study with an eddy-resolving model to evaluate chronic impacts in CO_2 ocean sequestration. International J. Greenhouse Gas Control, 2(1), 89–94, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[6] B. A. Megrey, Rose, K.A., Ito, S-I., Hay, D.E., Werner, F.E., Yamanaka, Y., and Aita, M.N.: North Pacific basin-scale differences in lower and higher trophic level marine ecosystem responses to climate impacts using a nutrient-phytoplankton-zooplankton model coupled to a fish bioenergetics model. Ecological Modeling, 202, 196–210, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[7] M. J. Kishi, D. L. Eslinger , M. Kashiwai, B. A. Megrey, D. M. Ware, F. E. Werner, M. Aita-Noguchi, T. Azumaya, M. Fujii, S. Hashimoto, H. Iizumi, Y. Ishida, S. Kang, G. A. Kantakov, H. Kim, K. Komatsu,

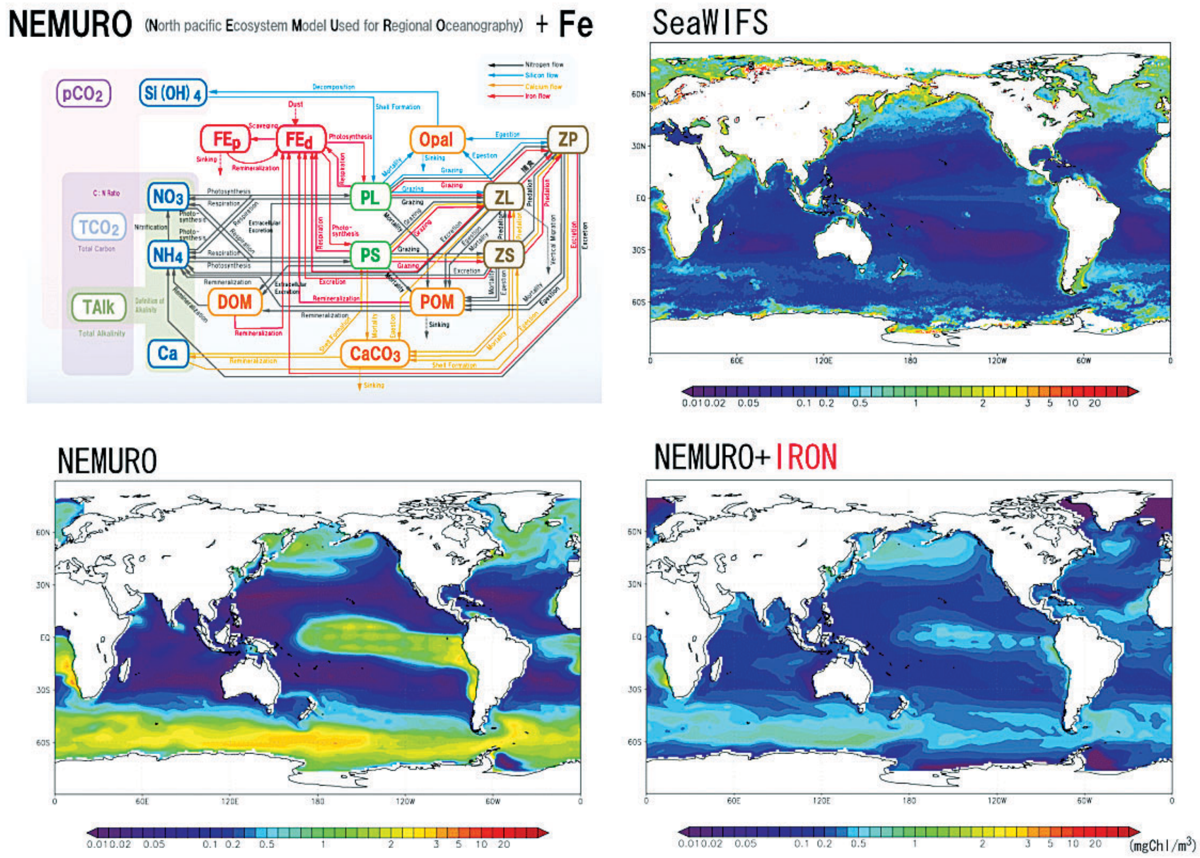

Fig. 4 Diagram of the ecosystem model (NEMURO) with iron cycle (top left). Annual mean chlorophyll-a from satellite observation (top right), the original version of the NEMURO model (low left) and the NEMURO model with iron cycle (low right).

V. V. Navrotsky, L. S. Smith, K. Tdokoro, A. Tsuda, O. Yamamura, Y. Yamanaka, K. Yokouchi, N. Yoshie, J. Zhang, Y. I. Zuenko, V. I. Zvalinsky: NEMURO - a lower trophic level model for the North Pacific marine ecosystem. Ecological Modeling, 202, 12–25, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[8] K. A. Rose, F. Werner, B. A. Megrey, M. N. Aita, Y. Yamanaka, D. Hay, J. Schweigert, M. B. Foster: Simulated Herring Growth Responses in the Northeastern Pacific to Historic Temperature and Zooplankton Conditions Generated by the 3-Dimensional NEMURO Nutrient-Phytoplankton-Zooplankton Model. Ecological Modeling, 202, 184–195, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[9] M. N. Aita, Y. Yamanaka, M. J. Kishi: Interdecadal Variation of the Lower Trophic Ecosystem in the Northern Pacific between 1948 and 2002, in a 3-D implementation of the NEMURO model. Ecological Modeling, 202, 81–94, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

[10] S. Ito, B. A. Megrey, M. J. Kishi, D. Mukai, Y. Kurita, Y. Ueno, Y. Yamanaka: On the interannual variability of the growth of Pacific saury (Cololabis saira): a simple 3-box model using NEMURO.FISH. Ecological Modeling, 202, 174–183, doi:10.1016/j.ecolmodel.2006.09.016, 2007.

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
和田英太郎　　海洋研究開発機構　地球環境フロンティア研究センター

著者
山中　康裕*[1]，石田　明生*[1]，笹井　義一*[1]，野口　真希*[1]，増田　良帆*[2]
＊1　海洋研究開発機構　地球環境フロンティア研究センター
＊2　北海道大学　大学院地球環境科学研究科

本プロジェクトは、海洋生態系と物質循環を組み込んだ海洋大循環モデルを用いて、産業革命から現在までの生態系変動の診断と現在から100年後までの将来予測に関する研究を行うものである。空間解像度や複雑さの異なる生態系モデルを用いた実験結果の相互比較・解析を通じて、海洋酸性化による生態系への影響や、海洋による二酸化炭素吸収量についての将来予測の高精度化を目指す。今年度は超高解像度の海洋大循環モデル(OFES, Ocean general circulation model For the Earth Simulator)に、比較的簡単な生態系モデル(NPZD, Nutrient-Phytoplankton-Zooplankton-Detritus)を結合させたモデルによる数値実験から、東部熱帯太平洋の渦の発達に伴う生態系変動や、黒潮続流域での蛇行や渦変動によるクロロフィル変動を解析した。また、解像度依存性を調べるため、昨年度開発した海氷過程を含むOIFES(Ocean-Sea-Ice GCM for the Earth Simulator)にNPZDモデルやトレーサーを組み込んだモデルにより、解像度の違いによるフロンの再現性の違いを調べた。また、OFESにより得られた海洋循環場を用いて海洋中層への二酸化炭素注入実験を行い、中規模渦による二酸化炭素の移流や拡散過程について成果をまとめた。さらに、複雑さの異なる生態系の影響を調べるため、より現実に近い生態系過程を再現できるNEMUROモデル(North pacific Ecosystem Model Used for Regional Oceanography)を、海洋大循環モデルCOCO(CCSR Ocean Component Model)に結合させたモデルによる、生態系・炭素循環再現実験を行い、モデル結果が近年の海洋表層における二酸化炭素濃度の上昇や酸性化をよく再現していること、北太平洋における10年規模の気候変動及びそれに対応した海洋生態系変動によって、二酸化炭素フラックスにも長期変動が見られることが分かった。今後、気候変動・生態系変動・海洋による二酸化炭素吸収量の変動の関係を理解するために、更に解析を進める計画である。

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