Mixed Layer Controls on Ocean Carbon Cycling and Ocean Acidification

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The development of buoy-based autonomous carbon sensors has improved our ability to examine ocean carbon cycle dynamics and ocean acidification on time scales ranging from days to years. Processes contributing to mixed layer carbon inventory changes can be quantitatively assessed to understand the relative importance of physics, chemistry, and biology while helping us to better understand the magnitude of long-term change in the context of natural variability. Here we compare two North Pacific time series sites: The Kuroshio Extension Observatory (KEO) in the western subtropical North Pacific and Ocean Station Papa in the eastern subpolar North Pacific. Preliminary results at KEO indicate that 4.5 ±2.2 mol C m^{-2} yr^{-1} is exported as organic carbon and 0.4 ±1.1 mol C m^{-2} yr^{-1} is exported as calcium carbonate, with much of the export occurring during the spring bloom. At Papa, the organic and inorganic carbon exports are 2 ±1 and 0.3 ±0.3 mol C m^{-2} yr^{-1}, respectively. Unlike KEO, export at Papa is spread out over the spring and summer months, then switches to net heterotrophy during the winter. Net organic carbon export at KEO is twice that of Papa, but the particulate inorganic carbon to particulate organic carbon ratio at Papa is about twice that of KEO. Observations suggest that both sites experience present day surface pH and Ω_{arag} conditions outside the bounds of pre-industrial variability throughout the year.

Keywords: carbon cycle, North Pacific, ocean acidification

太平洋西部赤道域における過去30年間の海洋酸性化傾向
The ocean acidification trend in the western equatorial Pacific for the past three decades

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The western zone of the tropical Pacific Ocean includes the “Coral Triangle”, which comprises the most important coral habitats on Earth with maximum marine biodiversity. One of the emerging issues that broadly threatens the coral reef ecosystems over the tropical and subtropical oceans is ocean acidification. Acidification is the consequence of not only the approximately 25% anthropogenic CO_2 emissions being absorbed by the ocean, but also with land use changes. A direct manifestation is the lowering of the pH of the ocean (increasing acidity) and the saturation level of the calcium carbonate minerals aragonite and calcite, which are important components of skeletal materials for many marine organisms including corals. Here we demonstrate the occurrence of ocean acidification in the warm western equatorial zone of the Pacific with the data of CO_2 system measurements over the past ~30 years since mid-1980s. In surface water within 125ºE-160ºW, 5ºS-5ºN, the partial pressure of CO_2 was increasing at a mean rate of +1.15 ±0.08 µatm yr^{-1} while that in the atmosphere was +1.74 ±0.01 µatm yr^{-1}. Total alkalinity, being salinity-normalized at S=35, has not shown any significant trend towards increasing or decreasing levels since early 1990 (NTA = 2296.6 ±3.8 µmol kg^{-1}). They are indicative of the increase in salinity-normalized dissolved inorganic carbon (NDIC) at +0.67 ±0.08 µmol kg^{-1} yr^{-1}, lowering of pH at -0.0011±0.0001 yr^{-1} and a reduction of saturation index of aragonite (Ωarag) and calicite (Ωarag) at -0.0097±0.0007 yr^{-1} and -0.0064±0.0005 yr^{-1}, respectively. The trend towards increased preformed_NDIC (+0.63 ±0.11 to +0.73 ±0.12 µmol kg^{-1} yr^{-1}) has also been observed on density classes of 23.0 –25.5σ_θ in the Equatorial Undercurrent that delivers waters to the equatorial divergence, and subsequently through transport in the South Equatorial Current to the surface of the warm western zone. Results of the measurements and numerical simulations with an ocean biogeochemistry / general circulation model suggest that equatorward transport of anthropogenic CO_2 by the shallow meridional overturning circulation from both hemispheres is an important process for the acidification in the equatorial Pacific. It is subsequently transported back into the subtropics and is considered to be contributing to the CO_2 increase and ocean acidification in the surface layers of the subtropical ocean.

キーワード：海洋酸性化、太平洋赤道域
Keywords: ocean acidification, equatorial Pacific

溶存鉄の除去過程としてのコロイダルパンピングのモデリング
Colloidal pumping as a removal process of dissolved iron: a model study

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Iron cycle is incorporated in many ocean models as its importance to marine organisms. The models, however, tends to overestimate dissolved iron (dFe) concentrations in large dust deposition areas. Such overestimation can be attributed to inappropriate formulation of iron removal where the rates are calculated as a first order function to the simulated dFe. Although some models assume higher order functions to estimate the removal rates, there is no scientific basis to explain the representations. It is known that adsorption of dissolved thorium (dTh) to colloids and subsequent coagulation (so-called “colloidal pumping”) is important to remove dTh. As colloidal iron is observed in various locations, “colloidal pumping” can play an important role on iron scavenging. This study aims to build a new iron scavenging parameterization based on “colloidal pumping”. A mechanistic model to calculate a coupled adsorption/coagulation process is described in Burd et al. (2000) and is applied to dTh scavenging. We firstly conducted an experiment using their model to highlight an importance of “colloidal pumping”. In this experiment, we suppose an open-ocean box having a typical ^{238}U concentration that produces ^{234}Th by radioactive decay. Colloidal particles (< 1 μm) are continuously added to the box, and the model is run to be a steady state. Increase in colloidal particles results in colloidal coagulation and thus formation of particles. Simulated outgoing ^{234}Th fluxes are mainly seen in diameters larger than 1 μm where the gravitational settling is significant. We then conducted an experiment without adsorption of dTh to colloids, namely turn off “colloidal pumping”. As dTh is removed only by adsorption directly to large aggregates, removal efficiency is much decreased and the simulated dTh concentration becomes several times higher. The result suggests that ignoring “colloidal pumping” results in overestimation of dissolved metals in ocean models.

キーワード：コロイダルパンピング、鉄、栄養塩、スキャベンジング
Keywords: Colloidal pumping, Iron, Nutrients, Scavenging

海洋低次生態系モデルへの亜硝酸塩の導入
Development of a marine ecosystem model including nitrite

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Nitrite is an intermediate product during nitrification and denitrification. Few marine ecosystem models including nitrite have been developed. However, many phytoplankton species have been observed to assimilate and release significant amounts of nitrite, although those processes are not well understood. The lack of these processes may cause uncertainty about predictions of primary production. As nitrite is a precursor of nitrous oxide (N_2O), which is a significant anthropogenic greenhouse gas and a stratospheric ozone destroyer, a marine ecosystem model including nitrite is also necessary for development of a marine N_2O model as a base model. In this study, a 1D marine ecosystem model including nitrite was developed, in order to understand the nitrite production and consumption processes quantitatively and to develop the relevant equations. We applied this model to the JAMSTEC time-series subarctic and subtropical sites (K2 and S1) in the western north Pacific. The nitrite concentrations observed at the highly productive K2 site during 20 cruises from 2004 to 2014 were relatively high (0.0-1.0 μM), and with maxima observed around σ_θ=26.4 kg/m^3 throughout the year. The nitrite concentrations observed at the less productive S1 site during 19 cruises from 2010 to 2014 were relatively low (0.0-0.5 μM) with maxima observed around σ_θ=25.0 kg/m^3 throughout the year. Nitrification rates determined by ^{15}N-labeling during the cruises in June 2013 and in July 2014 were 0-34 nmolN/L/day in at K2, and 0-11 nmolN/L/day at S1. Maximum rates were observed around σ_θ=26.4 kg/m^3 at K2 and σ_θ=25.1 at S1, consistent with the density at which nitrite was maximal. These results suggest that active production and remineralization cause nitrite accumulate at K2 more than at S1. Our model was validated with observed nitrate, ammonium, nitrite, and chlorophyll *a* concentrations and nitrification rates at K2 and S1. The model successfully simulated the higher nutrient and chlorophyll *a* concentrations and nitrification rates at K2 compared with S1, and also represented the subsurface maxima of nitrite and ammonium concentrations and nitrification rate. Case studies were conducted to test different formulations for the equations in this model. In the case without photoinhibition of nitrification, the simulated densities of nitrite, ammonium, and nitrification maxima are much shallower than observed at both stations. Surface nitrification rates could be measured at K2 because nitrate is not depleted at the surface, and the rates were not detected at depths sallower than 40 m. However, simulated surface nitrification rates were 6-13 nmolN/L/day in the case without photoinhibition of nitrification. These results suggest that our previous model, which did not include photoinhibition of nitrification, may underestimate the nitrite and ammonium concentrations in the euphotic layer and the regeneration rate. In this presentation, we will also show the differences in densities of nitrification and nitrite maxima and regeneration rate as obtained using the different equations for nitrification as applied in various existing marine ecosystem models.

キーワード：海洋生態系モデル、海洋窒素循環、亜硝酸
Keywords: Marine ecosystem model, Marine Nitrogen Cycle, Nitrite

植物プランクトンの成長制限に基づく全球海洋の生物地球化学的区分
Biogeochemical classification of the global ocean based on phytoplankton growth limitation

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A biological province provides an integrated view of regional characteristics of marine ecosystem and surrounding environment. Various definitions of biological province have been proposed based on regional differences in seasonal variation of satellite derived chlorophyll-a concentration and physical environments represented by temperature and salinity. In this decade, several new biogeochemical data that characterize regional difference in marine ecosystem became available. One is an estimation of phytoplankton community structure from satellite observation. Another is an estimation of limitation factors of phytoplankton growth from modeling studies. Particularly, nutrient limitations characterize regional difference in biogeochemical mechanism, while temperature and light dependencies mainly characterize a latitudinal difference in phytoplankton growth. In our study, we propose a new biogeochemical classification as a combination between the global distributions of the dominant phytoplankton group and their nutrient limitation. Namely, our provinces provide information what type of phytoplankton is dominant/coexist in each region and what type of nutrient limitation is controlling the phytoplankton growth. To obtain a climatological view of nutrient limitation, we used not a specific model result, but a diagnostic estimation based on a classical relationship of nutrient limitation (Michaelis-Menten formula) with observed macronutrients from World Ocean Atlas 2013 and a multi-model median of iron/ammonium concentration from model intercomparison projects, Coupled Model Intercomparison Project (CMIP5) and MARine Ecosystem Model Intercomparison Project (MAREMIP). Based on our classification, it revealed that the background mechanism, i.e., limitation factor of phytoplankton growth, is regionally different even if the same type of phytoplankton dominates. On the other hand, even in the geographically separated regions that recognized as the different provinces in the previous studies based on chlorophyll variability, the similarity in biogeochemical mechanism among provinces has been found. This result suggests that the regions with different mechanism potentially responds to climate change differently, even if the current ecological property seems the same between provinces.

キーワード：海洋生態系、生物地球化学的海洋区、生態系モデリング
Keywords: Marine Ecosystem, Biogeochemical provinces, Ecosystem Modeling

Impact of physiological flexibility on the dynamics of phytoplankton biomass, production, and nutrient distribution in a 1-D model of the near-surface ocean

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We compare results from the recently developed FlexPFT (Flexible Phytoplankton Functional Type) model, which includes the flexible physiological response (i.e., photo-acclimtation) of phytoplankton, to those of a typical inflexible control PFT (CtrlPFT) model, as applied in most NPZD-type models. Both models have been embedded within the General Ocean Turbulence Model (GOTM), which is here applied as a 1-D (vertical) model of mixing and transport within the upper few hundred meters of the ocean. Simulations were conducted of two contrasting time-series observation sites in the North Pacific: subarctic stn. K2 (47 degrees N, 160 degrees E) and subtropical stn. S1 (30 degrees N, 145 degrees E), both of which are maintained by JAMSTEC: http://ebcrpa.jamstec.go.jp/k2s1/en/. The FlexPFT model is better able to reproduce consistently the observed vertical distributions of chlorophyll, primary production, and particulate organic nitrogen, compared to the CtrlPFT. This is because the FlexPFT accounts for changes in the chl:N:C ratio of biomass with changing environmental conditions. Therefore vertical profiles and seasonal response obtained from the FlexPFT differ substantially from those obtained from the CtrlPFT. Although the importance of photo-acclimation has long been recognized in subtropical regions, our results suggest that this process may also be quite important in subarctic regions as well. We discuss some implications of this result for understanding biogeochemical cycles and plankton ecosystems.

Keywords: plankton, physiology, ecosystem, model, photo-acclimation

Trophic amplification of ocean productivity trends under climate change

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Pronounced projected 21st century trends in regional oceanic net primary production (NPP) raise the prospect of significant redistributions of marine resources. Recent results further suggest that NPP changes may be amplified at higher trophic levels. Here, we use the Geophysical Fluid Dynamics Laboratory's Earth System Model coupled with the COBALT (Carbon, Ocean Biogeochemistry and Lower Trophics) plankton ecosystem model (ESM2M-COBALT) to assess the extent of trophic amplification and the mechanisms underlying it. We focus on projected changes in mesozooplankton production –a key prey item for forage fish and the larval stages of larger fish. Globally, mesozooplankton production was projected to decline by 7.9%, but changes in some regions approached 50% and were twice the size of projected NPP changes. Changes in three planktonic food web properties –zooplankton growth efficiency (ZGE), the trophic level of mesozooplankton (MESOTL), and the fraction of NPP consumed by zooplankton (zooplankton-phytoplankton coupling, ZPC), explain the projected amplification. We will also describe preliminary results relating projected changes mesozooplankton production to potential changes in fish catch.

Keywords: Climate Change, Primary Production, Mesozooplankton

Expanding our Knowledge on Copepod Community Structure in Subarctic and Subtropical Communities as Revealed by the Species Functional Traits

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In order to manage the effects of climate change on marine resources, a more thorough understanding of community structuring is desired. Here, we analyze copepod species data from the ODATE collection (3142 samples, 40 years, 10 ^{o} x 10^{o} area of the Oyashio-Kuroshio Transition System, east of Japan). The area hosts species characteristic of subarctic and subtropical communities. 163 copepod species were classified into five categorical functional traits (i.e., size, food, reproduction, thermal-affinity and coastal-offshore habitat), following online databases and local taxonomic keys. We observe an opposite hump-shaped relationship of species evenness (lower at mid-point) and functional diversity (Rao's Q) (higher at mid-point) with species richness. Subtropical Kuroshio communities tend to be richer with higher species evenness, and yet subarctic and transition waters tend to host communities of higher functional diversity. The distribution of trait values within each functional trait was further examined in relation to the species rank according to their abundance. In subtropical communities, the distribution of trait values in the species rank is homogenous, mirroring the average frequency of those trait values in the species pools. In contrast, in subarctic communities the distribution of trait values differs along the species rank, with dominant species (rank 1) having favorable trait values more often than expected by chance (i.e., frequency of the trait values in rank 1 higher than the average frequency of those trait values in the species pools). Our results suggest that subtropical communities may be niche-saturated towards the most adapted trait values, so that merely having those most adapted trait value confers no strong competitive advantage to a species.

Keywords: species diversity, functional diversity, functional trait, copepod, plankton

A new perspective on the foraging ecology of apex predators in the California Current: results from a fully coupled ecosystem model.

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Results from a fully coupled ecosystem model for the California Current Large Marine Ecosystem are used to describe the impact of environmental variability on the foraging ecology of its most abundant apex predator, California sea lions. The ecosystem model consists of a biogeochemical submodel embedded in a regional ocean circulation submodel, and both coupled with a multi-species individual-based submodel for forage fish (sardine and anchovy) and California sea lions. Sardine and anchovy are specifically included in the model as they represent important prey sources for California sea lions and exhibit significant interannual and decadal variability in population abundances. Output from a 20-year run (1989-2008) of the model demonstrates how different physical and biological processes control habitat utilization and foraging success of California sea lions on interannual time scales, with the dominant modes of variability linked to sardine abundance and coastal upwelling intensity. The results also illustrate how variability in environmental conditions, forage fish distribution, and prey assemblage affect sea lions feeding success. While specifically focusing on the foraging ecology of sea lions, the modeling framework has the ability to provide new and unique perspectives on trophic interactions in the California Current, or other regions where similar end-to-end ecosystem models may be implemented.

Keywords: Ecosystem model, Foraging ecology, California Current, Marine predators

1976-77レジームシフトがカリフォルニア海流域のカタクチイワシおよびマイワシに与えた影響
Simulated influence of the 1976-77 regime shift on anchovy and sardine in the California Current System

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The well-known 1976-77 regime shift in the Pacific Ocean affected many species in the California Current System (McGowan et al., 2003). Chavez et al. (2003) labeled the periods before and after the 1976-77 regime shift as a cool “anchovy regime” followed by a warm “sardine regime.” However, the responses and mechanisms for what happened in that period for the Northern anchovy (*Engraulis mordax*) and the Pacific sardine (*Sardinops caeruleus*) in the California Current remains elusive. In this study, we used a fully-coupled end-to-end model (Fiechter et al., 2015; Rose et al., 2015) to simulate the variation in population dynamics of anchovy and sardine for past 50 years. This model is a multi-species, spatially explicit (3D), time-evolving, and consists of four coupled submodels (hydrodynamics, Eulerian nutrient-phytoplankton-zooplankton-detritus (NPZD), an individual-based full life cycle anchovy and sardine model; agent-based fishery). The end-to-end and spatial detail features of the model allows us to not only simulate population dynamics but also to analyze the bottom up effects of environmental variation on the temporal and spatial dynamics of the populations.
Analysis of a 50-year historical simulation (1959-2008) showed that anchovy recruitment (survival to age-1) was lower just after 1977, while sardine recruitment was relatively unaffected by the regime shift. These different responses to the 1976-77 regime shift have been hypothesized to be a contributor to the species replacement from anchovy to sardine observed in the 1980s. The recruitment success of both species was influenced by the growth and survival of individuals in the larval stage. The modeled zooplankton density shift from high to low in 1976-77 was most drastic in winter in the coastal area. Anchovy larvae feed extensively in the winter in the coastal area, while sardine larvae were mainly distributed in the offshore area in the spring. The differential seasonal and spatial responses of zooplankton in the simulation caused anchovy recruitment to be more sensitive than sardine to the 1976-77 regime shift. The zooplankton shift itself was a result of the nutrient concentration changes in surface layer. Nutrient concentrations decreased from 1977 due to the weakening of both the coastal upwelling and mixed layer shoaling, which reduced the vertical nutrient flux from the bottom layer to the surface layer.
Our end-to-end modeling approach provided a consistent analysis that linked the climate regime shift to anchovy and sardine population responses. In addition, our results suggest a possible mechanism for the responses related to seasonal and spatial aspects of the nutrient dynamics affecting the food for larvae that lead to a negative effect on anchovy recruitment and relatively little response of sardine. These results support the idea that anchovy and sardine populations are controlled by the different environmental factors related to their differences in habitat niches (Rykaczewsk and Checkley, 2008).

キーワード：カリフォルニア海流、End-to-endモデル、レジームシフト
Keywords: California current system, End-to-end model, Regime shift

耳石の$\delta^{18}O$と海洋同化モデルを用いたマイワシの回遊履歴推定

Reproducing migration history of Japanese sardine using otolith $\delta^{18}O$ and a data assmilation model

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日本のマイワシ（*Sardinops melanostictus*）の資源量は10～数十年スケールで、大変動を繰り返してきた。この変動は海洋環境変化と密接な関係にあると考えられているものの、仲介するメカニズムに関する理解は不十分である。このメカニズムを調べる上で、個体の環境経験履歴という情報は非常に重要であるが、回遊魚であるマイワシにおいてそれを調べることは非常に難しい。そこで本研究では、個体の回遊履歴を再現することを目的とし、耳石$\delta^{18}O$と海洋同化モデルを用いた推定法の開発に取り組んだ。
多くの魚種の耳石の$\delta^{18}O$は形成時の周囲の海水の$\delta^{18}O$と水温に依存して決まるが、マイワシでは確認されていなかった。そこで14.5・18.6・22 ℃の３水温帯で、それぞれ一ヵ月間飼育した。摘出した耳石から直近の一ヵ月間に形成された領域をマイクロミルで削り出した。回収した粉末と飼育水の$\delta^{18}O$を測定した結果、耳石$\delta^{18}O$ = 海水$\delta^{18}O$ - 0.186*水温 + 2.77 (R^2 = 0.91）という回帰式が得られ、標準誤差は0.17 ‰であった。また、マイワシの分布する黒潮～親潮域表層における海水$\delta^{18}O$の観測例は少ない。そこで 2012～2015年に中央水研によって行われた浮魚類の分布調査および2015年9月の新青丸航海にて表層採水し、$\delta^{18}O$を測定した。その結果、海水$\delta^{18}O$は南北方向に大きく変化していること、および塩分と強い正の相関があること（海水$\delta^{18}O$ = 0.60*塩分 - 20.56 ,R^2 = 0.93）が確認された。これら二つの知見から、マイワシ耳石の$\delta^{18}O$がある値になるためには、ある限られた水温・塩分の場所にいる必要があることがわかる。
2014年9月に千島列島沖で採集したマイワシ当歳魚2個体の耳石を摘出し、樹脂に包埋した後、日輪解析をした。続いてマイクロミル等を用いて耳石縁辺部から中心部に向かって耳石の粉を連続的に採取していき、それぞれ$\delta^{18}O$を測定した。測定に超微量炭酸塩分析システムMICAL3cを用いた個体については10-15日、自動分析システムDELTA V Plusを用いた個体については10-40日という高い時間解像度で、耳石$\delta^{18}O$履歴が得られた。履歴の各$\delta^{18}O$値に対し、対応する日付のFRA-ROMSの0 m深水温・塩分分布を取り出した。各日において、耳石$\delta^{18}O$が分析値を取りうる水温・塩分の条件を満たす領域を分布の中から特定することで回遊履歴を復元した。
2個体について復元した回遊履歴はどちらも、黒潮親潮移行域から親潮域北部まで回遊していく様子が明瞭に示されていた。また、より高解像度で分析した個体については採集点の近傍を含む領域まで回遊していく様子が再現されていたことから、この手法は個体の回遊履歴の推定に非常に有効であると考えられた。しかしこの方法で得られる推定分布位置は、特に東西方向に大きく広がっているため、今後回遊モデル等、別手法を併用することで、さらに推定領域を絞っていく必要がある。

キーワード：マイワシ、耳石酸素安定同位体比、海洋同化モデル
Keywords: sardine, otolith oxygen stable isotope, data assimilation model

日本東方の亜熱帯―亜寒帯混合域におけるアルカリ度の季節変動

Seasonal variation in total alkalinity in subtropical-subpolar transition area off eastern Japan

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アルカリ度の季節変動は二酸化炭素分圧や全炭酸濃度のそれと比較して小さく、これまであまり研究されていなかった。今回、北海道から関東東方の太平洋で2011-2015年に、気象庁の観測船や白鳳丸で測定されたアルカリ度のデータを使用してアルカリ度の季節変動について解析を行った。このデータは1月2月を除く全ての月で観測値があり、季節変動を捉えることが可能である。
アルカリ度の変動のうち、降水や蒸発に伴う塩分の変動によるものを取り除くため、塩分35に規格化したnTA_{35} = TA * 35/*S*を計算した。表層のnTA_{35}は黒潮続流以南の亜熱帯域では季節を問わず2290-2300 μmol kg^{-1}で一定であった。また、北緯46度以北の亜寒帯域における5月から6月の観測では、表層(5-6°C)と冬季混合層の名残である亜表層の水温極小層(< 2°C)でともにnTA_{35}が2355-2370 μmol kg^{-1}であり、両者のnTA_{35}に有意な差はなかった。よって、この２海域ではnTA_{35}に大きな季節変動がないとみられる。一方、この２海域に挟まれた亜熱帯―亜寒帯混合域では、nTA_{35}が夏に低く冬に高い季節変動を示した。これは黒潮を起源とする亜熱帯系水が夏季に高緯度まで移流してくることを裏付けるものである。
この亜熱帯亜寒帯混合域で観測されたアルカリ度を、水温・塩分と経度からアルカリ度を回帰・推定する*Lee et al.* [2006]の式と比較した。両者は7月8月についてはよく一致していたが、3月や12月にはLeeらの式が観測値に対して20-30 μmol kg^{-1}の過大評価になっており、季節変動を正しく再現できなかった。これはLeeらが回帰に用いたGLODAPデータベースに所蔵されているデータが夏季のものに偏っていることが原因と考えられ、この海域でアルカリ度の正確な分布を把握するには、夏季以外のデータも活用する必要があると示された。発表では、もうひとつのアルカリ度推定式である*Takatani et al.* [2014]との比較も行う。

キーワード：炭素循環、海洋酸性化
Keywords: carbon cycle, ocean acidification

親潮域における溶存酸素の長期変動と周期変動とその西部北太平洋への広がり

Trends of oxygen with bidecadal oscillations in the Oyashio region and its propagation to the western North Pacific

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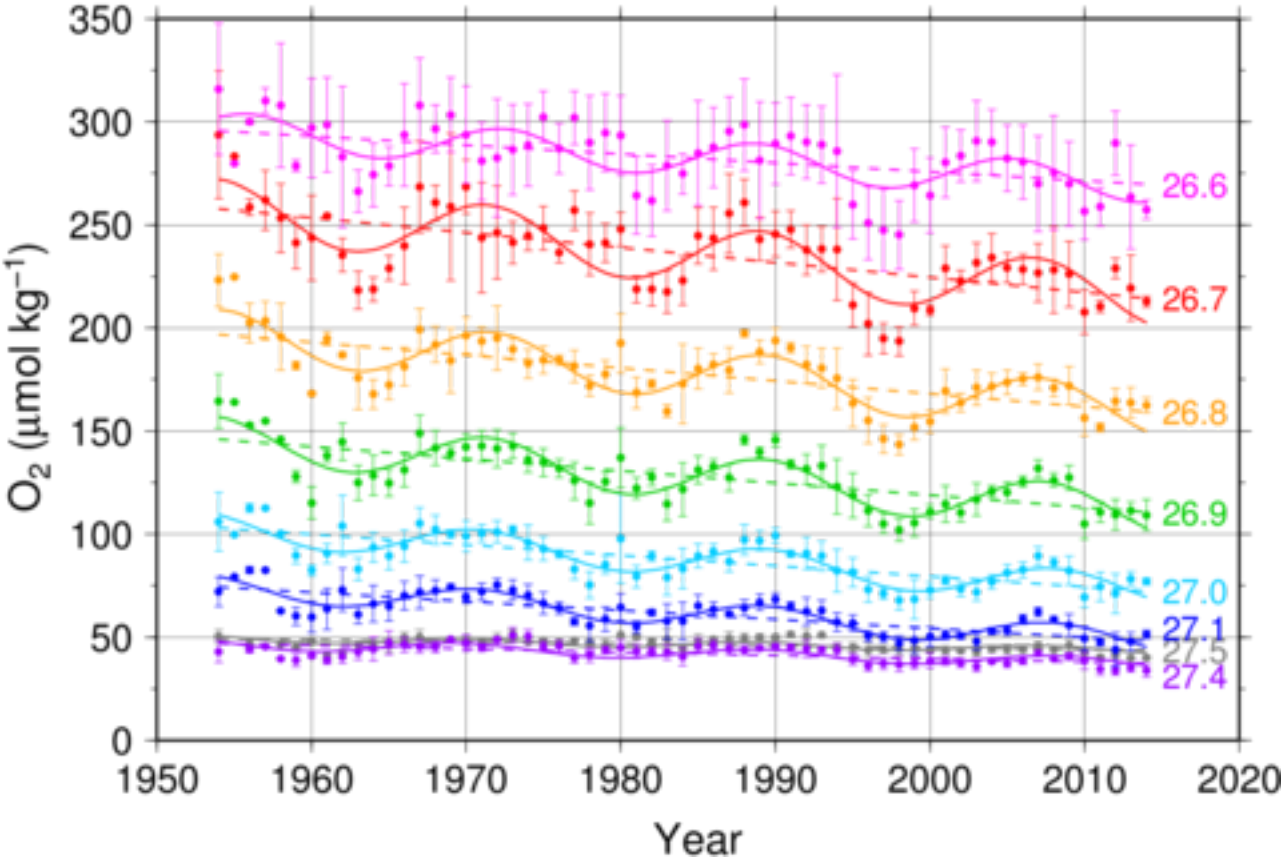
Over the past decades, secular trends toward decrease in dissolved O_2 have been observed in a variety of regions and depths in the North Pacific [Keeling et al., 2010, and references therein]. In the western North Pacific, O_2 decrease has been markedly found around 26.8σ_θ that corresponds to the core of North Pacific Intermediate Water (NPIW) along the 137°E section [Takatani et al., 2012] and the 165°E section [Sasano et al., 2015]. NPIW is formed in the subsurface of the Kuroshio-Oyashio Interfrontal Zone in the region offshore of northern Japan, and the Oyashio water is considered as one of the source of NPIW. In the Oyashio region, Ono et al. [2001] have found the trends toward increase in AOU and its bidecadal oscillations between 26.7σ_θ and 27.2σ_θ using time series data for the period of 1968–1998 in winter. They speculated that the reduction of ventilation caused the decreases in O_2. However, because the depth of isopycnal horizon of 27.2σ_θ is much deeper than that of 26.7σ_θ and does not outcrop in the western North Pacific, it is necessary to improve our understanding of these controlling factors. In this study, the controlling factors of secular trends in dissolved O_2 in the Oyashio region was investigated based on long-term hydrographic and biogeochemical measurements made over 1954–2014. We also evaluated the bidecadal oscillations in dissolved O_2 in the Oyashio region. Through the comparison of secular trends and bidecadal oscillations with those along the 165°E section, their propagation from the Oyashio region to the wide range of the western North Pacific was evaluated.
Significant linear trends toward decreasing O_2 were detected between 26.6σ_θ and 27.5σ_θ in the Oyashio region. The contribution of the decrease in the saturation concentration of O_2 due to warming was small (<10%). The largest decreasing rate in O_2 was found on 26.7σ_θ (-0.72 ±0.11 μmol kg^{-1} yr^{-1}) while it was attributed to a deepening effect of isopycnal horizons by approximately 33%. Because this density corresponds to temperature minimum layer formed in winter convection in the subarctic zone and surface density in winter has been decreasing, the decreasing O_2 around 26.7σ_θ would be predominantly attributed to the reduction of ventilation. At 27.0σ_θ, O_2 decline would be attributed to that in the Sea of Okhotsk where O_2 has been decreasing in this density due to the decrease in the formation of dense shelf water (DSW) in association with the decrease in sea ice forming. In deeper layers with densities up to 27.5σ_θ, O_2 decreases would also be explained by the reduction of DSW that propagates through diapycnal mixing in the Bussol' Strait. Furthermore, the O_2 reduction in deep layer might be attributed to the increasing contribution of Western Subarctic water through strengthening of the Aleutian Low. In the Oyashio region, bidecadal oscillations of O_2 have been observed in 26.6σ_θ–27.5σ_θ. The periodicities were almost constant at 16.4–19.6 years, and were vertically synchronized within 1 year. Along the 165°E section, the bidecadal oscillations were also found horizontally in 30°N–42.5°N on 26.8σ_θ with a time lag of 1–3 years from the Oyashio region, and vertically in 40°N up to the subtropical OML at 27.5σ_θ. It suggests that the bidecadal oscillations extended horizontally and vertically to the regions where the subarctic water influences. These results demonstrate that the western subarctic North Pacific is playing an important role as an origin for secular trends and natural variability in dissolved O_2.

キーワード：貧酸素化、20年規模周期変動、西部北太平洋
Keywords: deoxygenation, bidecadal oscillation, western North Pacific



地球温暖化に伴う溶存酸素の長期変動
Millennial-scale changes in dissolved oxygen due to global warming

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地球温暖化による海水温上昇と成層化，深層循環の弱化は海洋中の溶存酸素を全球的に減少させると考えられており，海洋生態系や物質循環への影響が懸念されている．中程度の複雑さを持つ気候モデルを用いた先行研究では，今世紀中に人為起源CO2 の放出が止まったとしても，深層水の遅いturnover の為に酸素濃度は1000年以上減少し続け，全球平均濃度は30%程度減少すると予想されている(Shaffer et al., 2009)．このような長期的な酸素濃度の変動は深層循環の応答に大きく依存するが，先行研究では積分期間が長い為に簡略化モデルを用いているため，深層循環の応答と溶存酸素濃度の変化について不確実性が大きいと考えられる．
本研究では，より現実的な海洋循環を表現するGCMを用いて温暖化実験を2000年積分した．また溶存酸素濃度の変化は，3次元offline 海洋物質循環モデルに上記のGCMで計算された海洋物理場を与えて計算した．これらの手法は，長期的な溶存酸素の変化について先行研究より信頼度の高い結果を提供すると期待される．
最初の500 年では，海水温上昇と成層化により全球平均の酸素濃度は20μmol/L 減少し，CMIP5 などの先行研究や一般的な予測と同じ結果になった.しかしその後，表層の酸素減少と大西洋子午面循環の弱化は続いているにも関わらず，中深層の酸素濃度は全球的に回復し，最終的に全球平均の酸素濃度は産業革命前の濃度よりも12μmol/L高くなった．この回復はウェッデル海の外洋で形成される深層対流が一時的に停止した後に回復し，深層に酸素が送り込まれた為に引き起こされることが分かった．GCM を長期積分することで，南大洋の海洋循環の応答が，百年スケールの酸素減少とは異なる千年スケールの酸素回復を引き起こす可能性が示された．ただし，現在の粗い解像度のGCM では南大洋の外洋域において対流を過大評価する傾向があるため(Heuzé et al., 2013)，不確実性が大きいことに留意する必要がある．
発表ではウェッデル海における深層対流の応答メカニズムについても議論する予定である．

キーワード：地球温暖化、溶存酸素、深層循環、海洋物質循環モデル
Keywords: Global warming, Dissolved oxygen, Deep ocean circulation, Ocean biogeochemical model

Measurement and mapping of dissolved methane distribution in the Sea of Japan: Influence of shallow gas hydrate deposits.

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Active methane seeps and shallow methane hydrate deposits are found in along the margins of the Sea of Japan. In this study, we installed several types of methane sensors on an ROV to determine dissolved gas concentrations in the water column as well as to map the distribution of concentrations near the seafloor. We first compare the performance of sensors from different manufacturers, then compare the results to actual water samples collected in vacuum bottles and in Niskin bottles. The recorded sensor data is then calibrated and compared with seafloor features recorded using the SeaXerocks mapping system developed at the University of Tokyo. The results show that high methane concentrations near the seafloor correspond to observed areas of microbial mats and exposed gas hydrate. The authors wish to acknowledge the crew and scientific staff of JAMSTEC that provided technical support during the 2014-2015 research seasons. This study was conducted as a part of the 2013-2015 shallow methane hydrate exploration project of the Ministry of Economy, Trade and Industry.

Keywords: methane hydrate, ROV, methane sensor

Diffusive benthic nutrient flux in the central of East China Sea

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To evaluate the importance of nutrient supply from sediment, phosphate, silicate, nitrate and nitrite in the porewater, overlying water, and entire water column were measured in the central of East China Sea. A measurement of multi-size particulate characterizing contour (LIIST) was carried out together with CTD casts also to quantify the influence of suspended particle. All nutrient concentrations in the porewater were greater than overlying water at stations B1 (32.9N, 126.0E) and C1 (32.7N, 124.8E), suggesting sediment was one of nutrient sources to the water column. Nutrient diffusion fluxes were calculated from the corresponding concentration gradients at these two stations, accounting for 20-60% of primary productivity. In contrast, at station C4 (31.2N, 126.0E), sediment was a nutrient sink. Bottom water at station C4 had low dissolved oxygen (DO, 1.8 ml/l), high weighted nutrients, and finest suspended particle relative to stations B1 and C1. Thereby, opposite nutrient diffusion at station C4 is most likely caused by organic matter remineralization at bottom water. However, phosphate concentrations at the bottom seawater were greater than the overlying water at all three stations. It might be affected by lateral transport near bottom or phosphate was absorbed by high concentration of particles at the seafloor. This study infers that nutrient flux from sediment to the overlying water, and further diffusion to the water column depends on the sediment property (e.g. grain size), in situ biogeochemical process and may associated with water transport.

Keywords: Porewater, Nutrient, Benthic flux, East China Sea

希土類元素による東シナ海陸棚水の水塊構造解析ー黒潮中層水の寄与

Water mass analysis using rare earth elements of shelf water in the East China Sea: contribution of Kuroshio Intermediate Water.

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To understand the origins and mixing of complicated water masses, as well as the contributions and nutrient supply via these various water masses in the East China Sea (ECS), a research cruise was conducted in the summer 2004. Water mass sources are defined by multiple tracers, including salinity and Rare Earth Elements (REE), etc. These sources include mixed shelf water (MSW, highest heavy REE concentration), Kuroshio surface water (KSW, highest temperature), Kuroshio tropical water (KTW, highest salinity), and Kuroshio intermediate water (KIW, highest nutrient content). High-nutrient water was identified in the middle shelf (bottom 100-130 m) and considered a mixture of MSW, KTW and KIW. The mixing ratios of three water sources are calculated using both conventional tracers (salinity and potential temperature) and four HREEs with the least squares method. Comparable results were obtained using these two datasets, suggesting HREEs, like temperature and salinity, are conservative comparing with water mass residence time and act as useful tracers to characterize the various water masses. The estimated KIW accounts for 26–55% of the middle shelf bottom water in the northernmost research area, while the proportion of NO_3+NO_2 from KIW is 55–81% and that of phosphate is 58–90%. This indicates that KIW is the major nutrient source in the bottom water of the middle ECS shelf.

キーワード：水塊構造解析、希土類元素、東シナ海
Keywords: water mass analysis, rare earth elements, East China Sea

海底鉱床掘削による重金属およびヒ素汚染リスクと海洋一次生産への影響評価
Risk of heavy metal and arsenic contaminations and its effect on marine phytoplankton during seafloor mining

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[Introduction]
Hydrothermal ore deposits are important as a metallic mineral sources. Many sulfide deposits containing Cu, As, Ag, Pb and Zn were found in the Exclusive Economic Zone of Japan. Recently, development of seafloor mining technology is advanced to use commercially those minerals. Environmental impact assessment is required because the seafloor mining could lead to marine environmental problems. For example, heavy metals and arsenic might be released from waste ore minerals during transfer of those from seafloor to vessel.
Here, we discuss about the possibility of heavy metal and arsenic contaminations and its effect on the primary production of marine phytoplankton during seafloor mining.
[Experimental]
Five types of chimney samples (G03, G04, G05, G06, and R04) which collected from hydrothermal fields of Iheya North Knoll and Izena Hole during the NT11-15 (Aug. 2011, R/V Natsushima) and NT12-06 (Mar. 2016) cruises with provided from JAMSSTEC. In the laboratory, the chimneys were powdered manually and sieved with a 1/16 mm mesh. Approximately 3.0 g of the powdered chimney was stirred into 30 mL of ultrapure water or artificial seawater (Daigo SP) in a Teflon centrifuge tube (50 cm^3), and then the tube was shaken at room temperature for 6 h. The solid phase was separated by centrifugation and filtration (0.2 μm). The metals dissolving in the solution were quantified by ICP-AES and ICP-MS.
Marine phytoplankton was incubated to evaluate the toxicity of the metals released from the chimney to the phytoplankton. Seawater was collected from subsurface chlorophyll maximum layer at hydrothermal fields of Iheya North Knoll and Bayonnaise Knoll during the KR15-17 (Nov. 2015, R/V Kairei) and KR15-20 (Dec. 2015), respectively. The solution reacted with the chimney G06 was added to the seawater and incubated for 18 h on the board. The chlorophyll fluorescence (F0) of the sample solution was determined by a pulse amplitude modulated (PAM) fluorometer.
[Results and Discussion]
Heavy metals such as Zn, Pb, Mn, Cd, and Cu and As were released from the chimney into the solution after the shaking with ultrapure water. The concentrations of Zn dissolving in the solution were between 41.7–1026.0 ppm. Arsenic (43.1 ppm) was the most abundant in the solution reacted with the chimney G05. Copper (61.6 ppm) was highly released from the chimney G06, whereas it was undetected from the other samples. The compositions of metals dissolving in the solutions were different from those of the chimneys. When the chimney was reacted with artificial seawater, the concentrations of heavy metals and arsenic dissolving in the solution were similar to ultrapure water. These results suggest that heavy metals and arsenic could be released from ore minerals to ocean during seafloor mining.
The chlorophyll fluorescence of seawater gradually decreased with time without addition of the solution reacted with the chimney G06. Marine phytoplankton living in the seawater collected from

the subsurface chlorophyll maximum layers would be unvigorous. When the solution reacted with the chimney G06 was added to the seawater (0.2 %), the chlorophyll fluorescence rapidly decreased with time. Therefore, the primary production of marine phytoplankton would be limited by heavy metals and arsenic released from ore minerals.

キーワード：海底鉱床掘削、植物プランンクトン、重金属汚染
Keywords: seafloor mining, marine phytoplankton, heavy metal contamination

数値シミュレーションを用いた播磨灘における冬季赤潮の消長機構の解明

Numerical simulation of the winter red tide of *Eucampia zodiacus* in the Harima-Nada

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沿岸域は、海洋の中でも人為起源の影響を大きく受ける領域であり、人間社会とのかかわりも密接な海域である。
特に、冬季の瀬戸内海（播磨灘など）では、最近数10年スケールで、海域の栄養塩が枯渇する「貧栄養化」という視点の問題が生じており、ノリの色落ち問題など、人間活動に直接影響を与える問題にまで発展している。
この数10年スケールの海域の栄養塩の変遷は、同じ時間スケールで生じている植物プランクトンの種の変遷と連動しているという仮説が考えられているが、これらの仮説は未だ解き明かされておらず、将来の環境変化（どのような種の変遷と水質の変化が起こるのか）も予測できていない状況である。
ここでは、冬季の播磨灘を対象にして、植物プランクトンを、小型の珪藻と大型の珪藻の2種類に分類した低次生態系モデルを用いた、栄養塩と植物プランクトンのブルームの時空間構造の再現計算を行った。
沿岸域の特徴としては、「水深が浅い」という特徴があるが、最近数10年で冬季のブルームが顕著となった大型珪藻は、海底到達後も光環境によっては死滅せず、巻き上げに伴って回帰する取り扱いを行うことで、パッチ状のブルームの規模とタイミングをよく再現できることが明らかとなった。
また、種の異なるパッチ状のブルームに対応して、栄養塩水質の時空間的な構造も捉えられている。
この結果は、仮説を基に構築したモデルを用いた現場データとの検証を行うことで、植物プランクトンの沿岸域スケールの競合の具体的な機構を解き明かしつつある事例でもあり、観測のみでは得られない情報をモデルを用いた数値実験により補間できた事例でもある。

キーワード：生態系モデル、珪藻、ユーカンピア、赤潮、播磨灘
Keywords: ecosystem model, diatom, Eucampia, red tide, Harima-Nada

黒潮域における植物プランクトン群集別基礎生産と動物プランクトン個体数密度との関係
Phytoplankton Community Structure and Zooplankton Abundance around The Kuroshio Western Boundary Current

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The Kuroshio is one of the largest western boundary currents in the world. In spite of the recognition of its importance on coastal fisheries in the Kuroshio waters, ecological mechanisms supporting fisheries production are poorly known. Recent marine ecosystem models made significant advancement in representing interactions among physical, biogeochemical and biological processes, yet interactions among different organisms within the biological processes is not necessarily well represented, mainly due to a lack of sufficient observation data required for modeling. Here we extended in situ observation of multiple phytoplankton groups into satellite observation and investigated their interactions with zooplankton such as copepods, using Artificial Neural Network. We found that phytoplankton (especially diatoms) played an important role in explaining zooplankton variability but only so in summer time in some waters. In winter-time, however, zooplankton abundance was rather independent of phytoplankton (chlorophyll) biomass (regardless of phytoplankton groups) and was largely explained by environmental factors such as a velocity of the Kuroshio. These results did not contradict the dilution-recoupling hypothesis, although a further investigation remains necessary to support the hypothesis.

キーワード：植物プランクトン、動物プランクトン、黒潮
Keywords: Phytoplankton , Zooplankton, Kuroshio

超貧栄養亜熱帯太平洋における生元素地理： どの存在形態が重要なのか？
Geography of biogenic elements in the super oligotrophic subtropical Pacific Ocean: What form is most important?

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Supply and dynamics of biogenic elements such as N, P, Si are essential marine processes to consider ocean domain since they are main control factors of biological productivity, ecosystem structure and biological pump. In marine ecosystems, most nutrients are supplied from deep water and the biological productivity is high in subarctic and upwelling regions. On the other hand, most part of subtropical waters are recognized as oligotrophic ecosystem with lower nutrient concentration than “detection limit” of conventional method of the analysis, e.g., <100 nM for NO_3 . In the oligotrophic subtropical waters, it has been suggested DOM contribute significant part of the supply of N and P supply and production, but the contribution of particulate matter is rarely studies. Recently, high-sensitive methods for nutrient measurement was developed (e.g., Hashihama et al., 2009) and found that the variations in nitrate and phosphate concentration were more than 3-order of magnitude in the western subtropical North Pacific. We developed the method of LWCC (Liquid Waveguide Capillary Cell) for nutrients into particulate forms of P and Si and also for DOP, and compared the inventory of each form in the Pacific Ocean. We found that variations in the concentrations of particulate N and P were within 2-order of magnitude and less variable than nutrients (5-order of magnitude). Our study suggests that particulate forms of P and N, including zooplankton, play important role as a source of biogenic elements in super-oligotrophic western subtropical gyre of the North Pacific. We will discuss contrastive biogenic elemental dynamics between subtropical and subarctic/upwelling ecosystems.

キーワード：亜熱帯太平洋、生元素、プランクトン
Keywords: subtropical Norht Pacific, biogenic elements, plankton

Optimality based models of phytoplankton size structure in the North Pacific

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Phytoplankton size structure is an important factor determining trophic transferand export production in the ocean. To model phytoplankton size structure,conventional ocean models usually discretize the phytoplankton community intoa number of size classes, which is usually computing extensive. In addition, theflexible behaviors of phytoplankton physiology such as flexible intracellularnitrogen-to-carbon ratios and chlorophyll-to-carbon ratios should be alsoconsidered. Here we present a new ecosystem model which combines theflexible behavior of phytoplankton physiology and an innovative approach ofmodeling the mean and variance of a continuously distributed phytoplanktonsize. The key features of the new type of ecosystem model include: 1) A tradeoffexists phytoplankton photosynthesis and nitrogen uptake. Phytoplankton cellsare assumed to optimize the energy allocation between light harvesting andnitrogen uptake. 2) By assuming a continuous lognormal distribution ofphytoplankton size, key phytoplankton physiological parameters such asnutrient uptake rate, photosynthesis rate, minimal nutrient quota, etc. followvalidated size-scaling laws. Then the net growth rate of the bulk phytoplanktoncommunity can be expressed as a function of the net growth rate at mean log sizeand the second derivative of net growth rate evaluated at the mean log sizebased on moment closure approximations. 3) A killing-the-winner strategy isadopted to maintain phytoplankton size diversity. This model is coupled with a3D regional ocean circulation model (ROMS) in the North Pacific and canreproduce the large-scale patterns of oceanic circulation, temperature, andsalinity, nitrate and chlorophyll fields. As expected, nutrient concentration is themajor factor controlling distributions of phytoplankton mean size and sizevariance. Sensitivity analysis suggests that the ecosystem model is very sensitiveto the type of grazing functions and zooplankton mortality closure terms.

Keywords: Phytoplankton, Size, Modeling

東シナ海の夏の植物プランクトン群集の経年変化

Internannual Variability of Summer Phytoplankton Community in the East China Sea

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Interannual variability of summer phytoplankton community was examined with HPLC pigments in 2009, 2010, 2011 and 2013. On 2009 and 2013, diatom was dominated in high chlorophyll-a water, while on 2010 and 2011 smaller phytoplankton was dominated. It is expected that influence of high nitrate Changjiang river water was stronger on 2010 and 2011, while phosphate amount was higher in 2009 and 2013 and coastal upelling may stronger. The sourse of nutrients may be the cause of the dominance of different phytoplankton groups.

キーワード：植物プランクトン、河川水、栄養塩
Keywords: phytoplankton, river water, nutrients

低次海洋生態系モデル(3-D NSI-MEM)と遺伝的アルゴリズム(μGA)を用いたデータ同化
Data assimilated state variables of a lower trophic level marine ecosystem model (3-D NSI-MEM) by a micro-genetic algorithm in North Pacific

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Lower trophic level marine ecosystem models have become increasingly important for understanding marine ecological systems, but there are two main difficulties for improving simulation results of marine ecosystem models. Firstly, lower trophic level ecosystem models have recently had many parameters with state variables increasing. The difficulty of estimating adequate parameters have also increased. Unbalanced parameter sets often lead to numerical divergence. Secondly, it is difficult for ecosystem models with one kind of ecological parameter set to reproduce realistic situations (*e.g.*, distribution patterns of phytoplankton, timing of spring phytoplankton bloom and so on), especially when coupled to physical three-dimensional models. Because the characteristics of local species are different with various provinces in the ocean. To estimate optimal parameter sets and approximate model results to a realistic situation, we used data assimilative approach by a genetic algorithm with a three-dimensional lower trophic level marine ecosystem model.
The marine ecosystem model 'NSI-MEM' based on NEMURO has been developed in Japanese communities. The ecosystem model has 14 compartments including two phytoplankton functional groups (non-diatom small phytoplankton (PS) and diatoms (PL)). The model was extended three-dimensionally and worked offline with the environmental physical field obtained from another realistic physical 3-D model (MRI.COM) experiment. One of the focuses of this study is to approximate the PS and PL concentrations to the values estimated from satellite data in the North Pacific region in 1998. We divided the region (15~65°N, 120~160°E) into three provinces based on dominant species and nutrients limitation, and set different ecosystem parameters for each province. The optimal parameters were estimated by the similar method to that in Shigemitsu et al. (2012) that used one-dimensional NSI-MEM with a micro genetic algorithm.
The correlation of phytoplankton concentration between the model result and satellite data is totally larger than that in the result without the estimated optimal parameters. For seasonal analysis in 1998, the correlation becomes relatively larger especially in winter (January to March) and smaller in spring (April to May), compared to that without the parameter estimation. This is because the timing of phytoplankton spring bloom in the model domain is shifted to the early period, due to the data assimilation process. As a result, roughly speaking, the satellite data-based assimilation by the genetic algorithm can help the model results to improve. For future works, we should investigate the values of the estimated ecosystem parameters (*i.e.*, the consistency between the ecosystem parameters and the real ecology of phytoplankton).

キーワード：三次元低次生態系モデル、遺伝的アルゴリズムを用いたデータ同化、北太平洋域
Keywords: 3-D lower trophic level marine ecosystem model, Data assimilation by a micro-genetic algorithm, North Pacific

水産生物の環境履歴と水産資源変動
Environmental history of living marine resources and fluctuation of fisheries resources

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潮汐の18.6 年振動と同期した海水中の栄養塩や酸素濃度の約20 年周期変動が、亜寒帯海域や亜熱帯海域で観測されている一方、日本周辺の水産資源にも約20 年周期変動やその約3 倍の50-70 年周期変動（マイワシ・マサバ・マアジ等）が卓越し、潮汐振動に起因する気候、水塊や餌料の変動が水産資源の変動と連動している可能性が高い。西部北太平洋海域で確認されている潮汐振動に起因する事象のつながりを明らかすることは、栄養塩循環，生態系，水産資源の長期変動過程の理解や予測可能性を高めることにつながる。2015年度より、文部科学省科学研究費補助金・新学術領域研究「海洋混合学の創設：物質循環・気候・生態系の維持と長周期変動の解明」の計画研究として、「水産生物の環境履歴と水産資源変動」に関する研究を開始したので、その内容を報告する。潮汐振動などに起因する海洋鉛直混合の長期変動が、直接・間接的に水産資源変動に与える影響を、耳石日輪の高解像度同位体分析による稚仔魚の環境履歴復元と生態系魚類モデルを用いた解析により明らかにすることを目的としている。

キーワード：海洋混合、長周期変動、海洋生態系モデル、魚類成長－回遊モデル
Keywords: ocean mixing, long term fluctuation, ecosystem model, fish growth-migration model

東シナ海におけるカタクチイワシの温暖化影響評価の試みII

A challenge to evaluate effect of climate change on Japanese anchovy (*Engraulis japonicus*) in the East China Sea II

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海洋大循環モデルC-HOPE（Max-Planck-Institute Ocean Model）と海洋低次栄養段階生態系モデルNEMURO（North Pacific Ecosystem Model for Understanding Regional Oceanography）の拡張版であるeNEMUROを結合させた、CHOPE-eNEMUROを現在気候外力と将来気候外力を用いて駆動し、現在と将来の水温、流向・流速、餌料プランクトン場を得、その場を用いてカタクチイワシの成長－回遊モデル（eNEMURO.FISH）を積分することで、地球温暖化が東シナ海のカタクチイワシに与える影響を評価している。これまでは、初期産卵場を、深度1000 m以浅で且つ水温15.6～27.8℃の海域に形成されると仮定し推定していたが、東シナ海のカタクチイワシの産卵場水温を再解析した結果、好適水温が14.1～20.1℃及び27.2～27.8℃の範囲にあるとの結果を得た。この新しい好適水温を仮定して初期産卵場を求め、産卵から1年間の計算を行った。また、これまでは3月生まれのカタクチイワシを対象としていたが、4および5月生まれのカタクチイワシについても同様の計算を行い、生まれ月による影響の違いも検討した。現在気候下では、九州西岸域に加入するシラスは、九州北部では4月生まれが、南部では3月生まれが主体となったが、将来気候下では、北部、南部とも3月生まれが主体となり、北部で1ヶ月シラス最盛期が早まる結果となった。また、体長に注目すると、現在気候下では、九州西岸域に加入するシラスは、北部では5月生まれ、南部では4月生まれがモード体長最大となるが、将来気候下では、北部では4月生まれ、南部では3月生まれがモード体長最大となり、モード体長が最大となる時期が1ヶ月早期化する結果となった。将来気候下では、4月の南部および5月の北部および南部に加入するシラスが激減したが、これは20.2～27.1℃の間に産卵場が形成されないという仮定のために、将来気候下では東シナ海の産卵場が消失したためである。今後は、東シナ海で20.2～27.1℃が好適水温帯にならない理由を精査する必要がある。

キーワード：海洋生態系モデル、魚類成長－回遊モデル、カタクチイワシ、地球温暖化
Keywords: ecosystem model, fish growth-migration model, Japanese anchovy, climate change

