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

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.

Keywords: ocean acidification, equatorial Pacific

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.

Keywords: Colloidal pumping, Iron, Nutrients, Scavenging

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.

Keywords: Marine ecosystem model, Marine Nitrogen Cycle, Nitrite

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.

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 ° x 10° 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

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).

Keywords: California current system, End-to-end model, Regime shift

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

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Using the combination of otolith oxygen stable isotope ratio ($\delta^{18}O$) and data assimilation model, a new method to reproduce migration histories of Japanese sardine (*Sardinops melanostictus*) was developed. Firstly, dependence of otolith $\delta^{18}O$ on temperature was examined for the first time for Japanese sardine. Juveniles were reared in three different water temperature (14.6, 18.7, 22.0 °C) for a month. Sagittal otoliths were collected and areas formed in latest 28 days were extracted by micromill for $\delta^{18}O$ analysis. $\delta^{18}O$ of rearing water was also measured and a linear relationship between otolith $\delta^{18}O$ and temperature was determined as follows: $\delta_{otolith} = \delta_{water} - 0.186\ (T) + 2.770$, $r^2 = 0.91$ (1).
Secondly, the distribution of seawater $\delta^{18}O$ in the western North Pacific and relationship between salinity was investigated. During 2012-2015, surface water samples were taken from 90 different locations for $\delta^{18}O$ analyses. Surface $\delta^{18}O$ showed a clear poleward gradient and linear regression analysis revealed that $\delta^{18}O$ and salinity were strongly correlated: $\delta_{water} = 0.601(S) - 20.564$, $r^2 = 0.93$ (2), which enabled us to estimate seawater $\delta^{18}O$ from salinity. These results were essential to convert the otolith $\delta^{18}O$ profile into migration history. Micro-volume $\delta^{18}O$ analysis and our original microsampling technique enabled us to extract otolith $\delta^{18}O$ profile in a temporal resolution of 10-15days through whole life of juveniles approximately 200 days post hatch. For dates corresponding to each value of the profile, surface temperature and salinity in the range of 30-55 °N, 130-180 °E were extracted from FRA-ROMS, a data assimilation ocean model which reproduce ocean environment realistically. Temperature and salinity in each grid were converted into otolith $\delta^{18}O$ value using Eq. (1) and (2). Grids in which the calculated otolith $\delta^{18}O$ value was equivalent to actually analyzed value were considered to be the location of the individual on the date. Movements of the juveniles reproduced by this method clearly showed the northward migration from the Kuroshio-Oyashio transition zone to the Oyashio region and the estimated location on the date approached to the actual sampling point, which indicated the high accuracy of the method.

Keywords: sardine, otolith oxygen stable isotope, data assimilation model

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

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Seasonal variation in total alkalinity has been insufficiently considered in discussing oceanic CO_2 system since it is smaller than that of the partial pressure of CO_2 and dissolved inorganic carbon. Here we compiled hydrographic observations in the western North Pacific off Japan (28–50°N, 140–165°E) for the period of 2011–2015. This dataset we use is sufficient to assess the seasonal variation of TA as it includes the discrete value of TA and related parameters (*e.g.* temperature, salinity and nutrients) in all months other than January and February.

We excluded the variation of TA being accompanied by the evaporation and precipitation of seawater by normalizing TA to salinity = 35 (nTA_{35} = TA*35/*S*). Surface nTA_{35} showed very little seasonal variation and were 2290–2300 μmol kg^{-1} in the subtropical region to the south of Kuroshio extension throughout the year. In subpolar region to the north of 46°N, data was seasonally confined in May and June. Surface nTA_{35} in subpolar region (5–6°C) was 2355–2370 μmol kg^{-1} and almost equivalent to that in subsurface temperature minimum layer (< 2°C) which corresponds to the remnant of the winter mixed layer. Therefore, the seasonal variation of TA was supposed to be small in the subpolar region. In subtropical-subpolar transition area between these two regions, however, nTA_{35} showed considerable seasonal variation as large as 80 μmol kg^{-1}. It was lower in summer while higher in winter. This indicated the intrusion subtropical water with low nTA_{35} to higher latitude in summer.

We compared observed TA in the transition area with estimated TA by multiple linear regressions by *Lee et al.* [2006]. There were no large discrepancies between estimated TA and observed TA in June and August. However, estimated TA was significantly larger than observed TA by 20–30 μmol kg^{-1} in March and December. This inconsistency in winter was possibly due to the seasonal bias in the dataset stored in GLODAP database which was applied to make regressions in *Lee et al.* [2006]. In order to reproduce the seasonal variation in TA subtropical-subpolar transition area properly, it is essential to consider the data in other than summer.

We will also discuss the difference between observed TA and estimated TA from another regression given by *Takatani et al.* [2014].

Keywords: carbon cycle, ocean acidification

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

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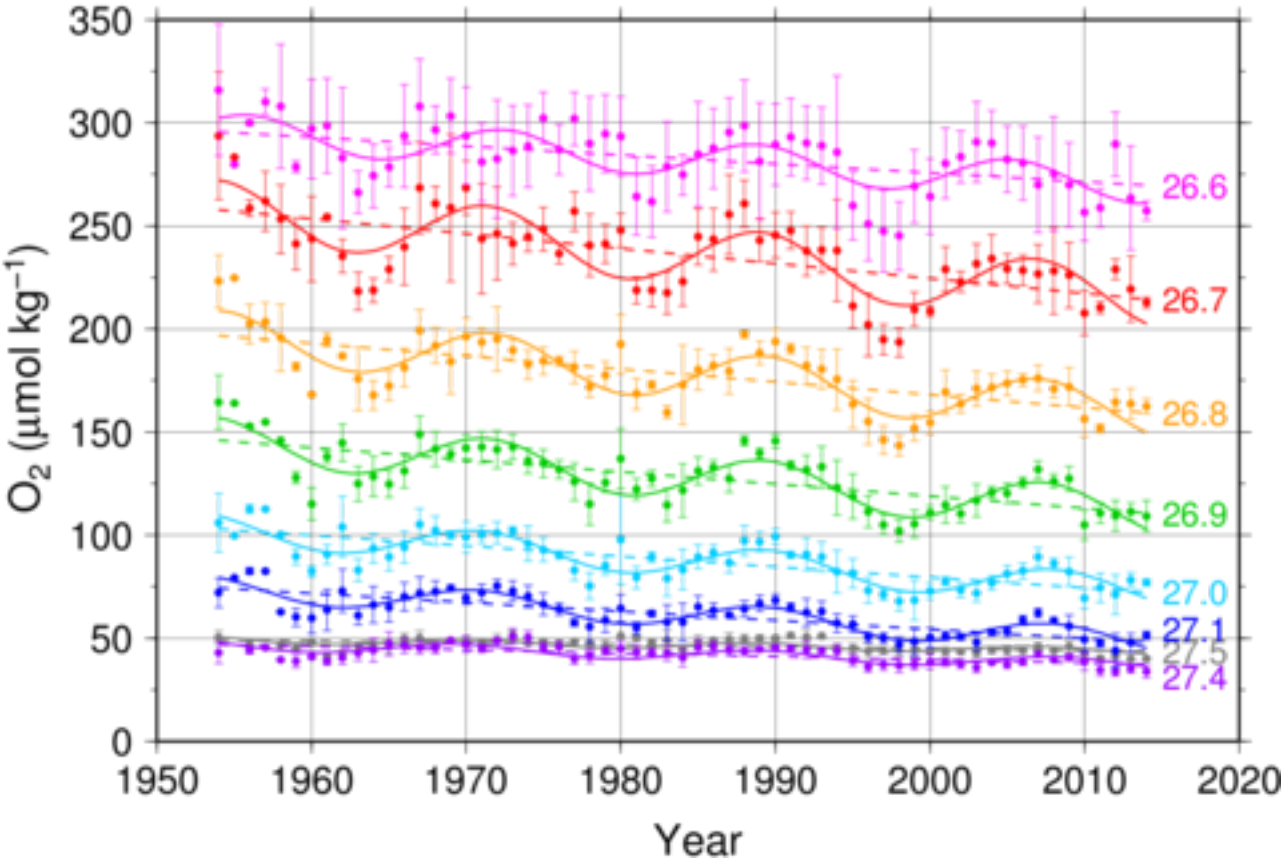
Over the past decades, secular trends toward decrease in dissolved O_2 have been observed in a variety of regions and depths in the North Pacific [Keeling et al., 2010, and references therein]. In the western North Pacific, O_2 decrease has been markedly found around 26.8σ_θ that corresponds to the core 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.

Keywords: deoxygenation, bidecadal oscillation, western North Pacific



Millennial-scale changes in dissolved oxygen due to global warming

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Global warming is expected to globally decrease ocean oxygen concentrations by sea surface warming and ocean circulation change. Oxygen reduction is expected to persist for a thousand years or more, even after atmospheric carbon dioxide stops rising. However, long-term changes in ocean oxygen and circulation are still unclear. Here we simulate multimillennium changes in ocean circulation and oxygen under doubling and quadrupling of atmospheric carbon dioxide, using GCM (MIROC) and an offline biogeochemical model. In the first 500 years, global oxygen concentration decreases, consistent with previous studies. Thereafter, however, the oxygen concentration in the deep ocean globally recovers and overshoots at the end of the simulations, despite surface oxygen decrease and weaker AMOC. This is because, after the initial cessation, the recovery and overshooting of deep ocean convection in the Weddell Sea enhance ventilation and supply oxygen-rich surface waters to deep ocean. Another contributor to deep ocean oxygenation is seawater warming, which reduces the export production and shifts the organic matter remineralization to the upper water column. Our results indicate that the change in ocean circulation in the Southern Ocean potentially drives millennial-scale oxygenation in deep ocean, which is opposite to the centennial-scale global oxygen reduction and general expectation. In presentation, we will discuss the mechanism of response of deep ocean convection in the Weddell Sea.

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

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.

Keywords: water mass analysis, rare earth elements, East China Sea

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.

Keywords: seafloor mining, marine phytoplankton, heavy metal contamination

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

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A coastal region is closely linked human society, and it is very influenced by anthropogenic effects.
Especially, oligotrophic waters became a problem last few decade in Harima-Nada.
The oligotrophic waters in Harima-Nada is considered that related to changes of species composition of phytoplankton.
Here, the bloom of *Eucampia zodiacus* and distribution of DIN in Harima-Nada were calucurated by used of the numerical simulation model.

Keywords: ecosystem model, diatom, Eucampia, red tide, Harima-Nada

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.

Keywords: Phytoplankton , Zooplankton, Kuroshio

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.

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

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.

Keywords: phytoplankton, river water, nutrients

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).

Keywords: 3-D lower trophic level marine ecosystem model, Data assimilation by a micro-genetic algorithm, North Pacific

Environmental history of living marine resources and fluctuation of fisheries resources

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While about 20-year periodic fluctuation of seawater nutrient and oxygen concentrations synchronous with 18.6-year nodal tide have been observed in the subarctic and subtropical oceans in the North Pacific, fisheries resources around Japan showed 20-year and about three times 50-70 years (sardine, common mackerel, jack mackerel, etc.) fluctuations. There is a possibility that the 18.6-year nodal tide effects on the fisheries resources fluctuations through climate, water mass formation, and prey plankton productions. For comprehensive understandings and high skill predictability of long-term fluctuations of nutrient cycles, marine ecosystems, and fisheries resources, it is important to elucidate the mechanisms of phenomena connected to 18.6-year nodal tide. In 2015, a new project entitled “Ocean mixing processes (OMIX), impact on biogeochemistry, climate and ecosystem” started. As a planning research “Environmental history of living marine resources and fluctuation of fisheries resources” was formed. In this presentation, we will introduce the study plan. We aim to elucidate direct and indirect influences of the long-term fluctuation of ocean mixing processes caused by 18.6-year nodal tide on fisheries resources by high resolution isotope analysis of fish juvenile otoliths and marine ecosystem-fish coupled models.

Keywords: ocean mixing, long term fluctuation, ecosystem model, fish growth-migration model

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

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We have evaluated climate change (global warming) effects on Japanese anchovy in the East China Sea by integrating a fish-migration and growth model using environmental conditions derived from simulations of a coupled ocean circulation and ecosystem model with current and future climate forcing. For the ocean circulation model, CHOPE (Max-Planck-Institute Ocean Model) was used. For the marine ecosystem model, eNEMURO, an extended version of NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) was used.
The initial spawning grounds were assumed in the area which depth is less than 1000 m and the sea surface temperature (SST) is between 15.6 and 27.8 degC in the previous study. However, a new analysis of water temperature of egg distribution showed higher probability in the region which SST is between 14.1 and 20.1 degC and 27.2 and 27.8 degC. The spawning area was estimated using the new temperature criteria and the fish growth and migration model was integrated for one year since the spawning. In addition, although the spawning timing was assumed in March in the previous study, we conducted the simulations for anchovy spawned in April and May and investigated the dependency on the spawning timing.
Under the contemporary condition, the number of anchovy larvae advected to the northwestern side of Kyushu (NWK) showed the maximum in April, while it showed the maximum in March in the southwestern side of Kyushu (SWK). However, under the future climate, it showed the maximum in March both in the NWK and SWK. Therefore, the peak timing was advanced in the NWK under the future condition. Regarding the body size, larvae advected to the NWK showed the maximum mode body length in May, while those advected to the SWK showed it in April under the contemporary condition. Under the future condition, the timing was advanced by one month (April in the NWK and March in the SWK). Under the future condition, the number of larvae advected to the SWK in April and May and those advected to the NWK in May were drastically decreased. This result heavily depends on the assumption that the spawning ground is not formed in the region which SST is between 20.2 and 27.1 degC. Under the future condition, the spawning ground was disappeared in the East China Sea. As a future work, the reason the spawning probability becomes lower in the region which SST is between 20.2 and 27.1 degC should be elucidated.

Keywords: ecosystem model, fish growth-migration model, Japanese anchovy, climate change

