Mapping of monthly climatology of global ocean surface nutrient by a feed forward neural network

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Feed forward neural network (FNN) is one of neural network families and a software applicable for oceanographic mapping has been developed by Zeng et al. [1]. The method has already been applied for sea surface fCO_2 mapping with SOCAT data products [2] and reasonable performance was obtained [1]. Since seasurface nutrients, such as phosphate, nitrate and silicate, are important parameters for ocean biogeochemical cycles, we tried application of FNN to global mapping of these nutrients combining several observational datasets. The dataset, having global coverage, is World Ocean Database 2013 by NODC/NOAA. In Pacific region, we have more detailed surface ocean datasets from ship-of-opportunity programs by NIES (National Institute for Environmental Studies, Japan) and IOS (Institute of Ocean Science, Canada). In this study we combined these data sets and some were added from Pacific hydrographic data set, PACIFICA (Pacific Ocean Interior Carbon dataset). Relationship between sea surface temperature, sea surface salinity, mixed layer depth and satellite observed chlorophyll-a were put into a coordinated format and the FNN was trained with the nutrient data sets with temporal and locational variables (month, latitude and longitude). Monthly climatological maps with 1x1 degree latitude and longitude resolution for phosphate, nitrate and silica were obtained and error of estimation was examined by comparison with the training datasets. The evaluation was feasible for oceanic regions of relatively high nutrient concentrations such as North Pacific, Southern Ocean, North Atlantic, and East Pacific Equatorial upwelling regions. The nitrate biases were −0.24±0.62, −0.27±0.72, −0.57±0.81, and −1.21±0.88 micro M, respectively for these oceanic regions. The performance was comparable for another mapping study using different neural network scheme by Yasunaka et al. for North Pacific [3], even this study was the global mapping. The larger bias and standard deviation for Equatorial Pacific should be caused by ENSO variability. Avoiding lack of high latitude coverage caused by missing satellite chlorophyll-a dataset in winter season, FNN estimation without chlorophyll-a dataset was evaluated for the three nutrients. Errors for nitrate and silicate changed seasonally, which were larger in summer and smaller in winter. This is due to relatively uniform distribution of the nutrients in winter overturning period and increasing patchness in productive summer period. However, error in phosphate estimation showed no seasonal change. Estimated map with and without chlorophyll-a showed some differences related probably due to biological productivity. We compared maps of silicate/nitrate ratio with and without chlorophyll-a dataset in the North Pacific. Higher silicate/nitrate ratio areas were detected in the subarctic north western Pacific HNLC region in late summer only in the maps with chlorophyll-a dataset. Figure 1 shows silicate/nitrate molar ratio for global ocean (upper panel), where silicate and nitrate concentrations are more than 4 and 2 micro M, respectively. Uniform ratio around 1.5 is observed in the high latitude North Pacific but more variability in the southern ocean of summer. Increasing silicate/nitrate ratio is observed in the western high latitude North Pacific in August and September. This may be related to the changing control of diatom productivity by micro nutrient supply.

[1] Zeng et al. (2014) JAOT 31, 1838-1849. [2] Pfeil et al. (2013) ESSD 5, 125-143. [3] Yasunaka et al. (2014) JGR 119, 7756-7771.

Keywords: mapping, nutrients, monthly climatology, global ocean surface, neural network

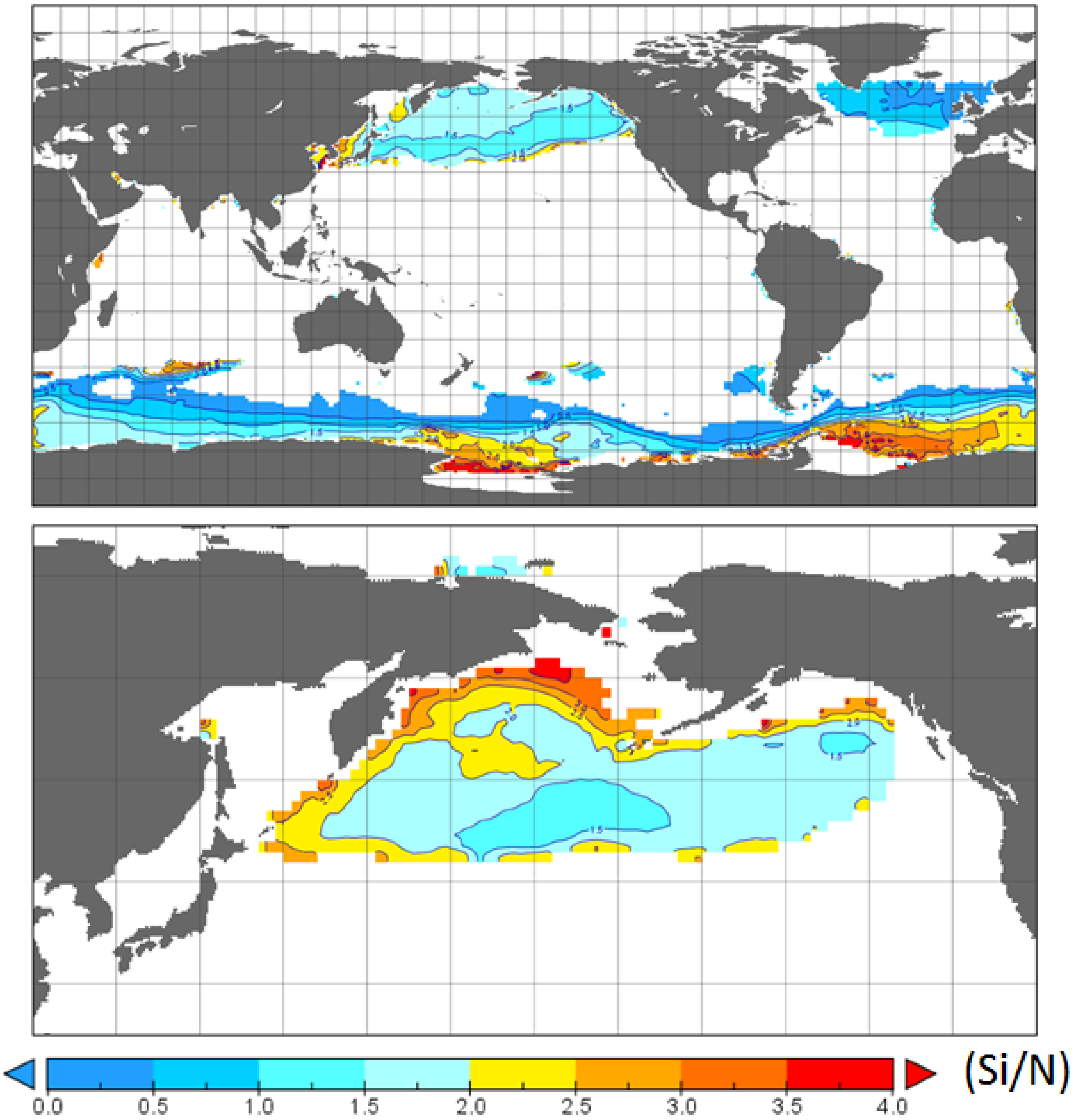

Figure 1. Silicate/nitrate molar ratio map of February for global ocean (upper panel) and August for North Pacific (lower panel) estimated by FNN

Development of a model of nitrous oxide in the western North Pacific

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Nitrous oxide (N_2O) is a greenhouse gas that also destroys the stratospheric ozone. It is important to estimate accurately the global N_2O budget in order to better understand the factors that influence atmospheric N_2O concentrations, to develop global warming countermeasures, and to protect the ozone layer. Previous models have indirectly predicted marine N_2O emissions from the apparent oxygen utilization, based on the observed inverse relationship between the dissolved oxygen and N_2O concentrations in the ocean. However, different microbes with distinctive substrates and enzymes mediate N_2O production and consumption processes. The accurate estimation of past, current and future marine N_2O emissions requires a model including these processes explicitly. In this study, a 1D marine ecosystem model that incorporates N_2O production processes (i.e., ammonium oxidation during nitrification and nitrite reduction during nitrifier denitrification) was developed. We applied this model to the JAMSTEC time-series subarctic and subtropical sites (K2 and S1) in the western north Pacific. The model was validated with observed nitrogen concentration and successfully simulated the higher N_2O concentration, the higher N_2O production rates, and the higher nitrification rates at K2 compared with S1. The annual mean N_2O emission fluxes were estimated to be 42 mgN m^{-2} yr^{-1} at K2 and 3 mgN m^{-2} yr^{-1} at S1. Using this model, we conducted two case studies: 1) estimating the ratio of N_2O emission flux by in-situ biological N_2O production to total flux, 2) estimating the ratio of N_2O production by ammonium oxidation to that by nitrite reduction. The results of case studies estimated the ratio of N_2O emission flux by in-situ biological N_2O production to be ˜68% at K2 and ˜100% at S1. It is also suggested that N_2O was mainly produced via ammonium oxidation at K2 but was produced via both ammonium oxidation and nitrite reduction at S1. Beman et al. (2010) suggested that ocean acidification could reduce nitrification rates and therefore affect oceanic N_2O production. In this presentation, we will also show the model results in the case of ocean acidification.

Cluster III *nifH*-harboring microbes dominated diazotroph communities in the Chukchi Sea (western Arctic Ocean)

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Marine nitrogen fixation is now considered to occur not only in subtropical and tropical regions but also in colder regions, although the extent of and the identity of diazotrophs responsible for nitrogen fixation in the Arctic Ocean remain poorly understood. Here we examined diazotroph community structure and activity in the Chukchi Sea, a marginal sea of the western Arctic, during summer 2015. The diazotroph community determined by Illumina sequencing was mainly composed of Cluster III *nifH* phylotypes (putative anaerobes), accounting for 60–100% of the total sequences examined except one surface sample. This result is strikingly different from the previous findings in other oceanic regions. The *nifH* sequences other than Cluster III were mostly affiliated with UCYN-A2 (symbiotic cyanobacteria), which accounted for less than 15% of the total sequences. Nitrogen fixation rates were measurable at all the stations, with the maximum rate of 1.84 nmol L-1 d-1. The nitrogen fixation rates varied in a complex manner, displaying no clear relationship with depth (light intensity) and nitrate concentrations. The nitrogen fixation rate exceeded the nitrate assimilation rate in some nitrate-depleted waters, indicating that the diazotrophs could be an important source of new nitrogen in the Chukchi Sea.

Keywords: Nitrogen fixation, Arctic Ocean, nifH gene

Surface peaks of primary production during summer in the oligotrophic open ocean: a modeling study

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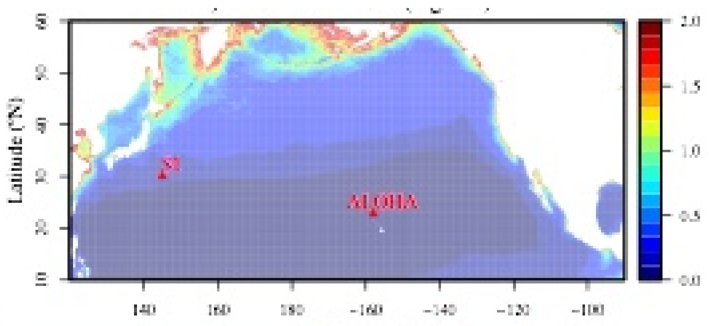
Classic understanding on the phytoplankton dynamics in the oligotrophic open ocean such as the central North Pacific gyre is that phytoplankton growth rate is limited by the upward supply of inorganic nutrients delivered largely by diffusion. Since nutrient supply mostly comes from below and light attenuates from surface to the depth, phytoplankton growth rate should peak at some intermediate depth, coinciding with the deep chlorophyll maximum (DCM) layer. However, examination on the data of net primary production (NPP) measured at two stations (ALOHA and S1) in the subtropical North Pacific reveals that NPP peaks within the surface mixed layer in spite of the negligible nutrient concentration at surface and a pronounced deep chlorophyll maximum (DCM) around 100 m. While the formation of DCM might be largely accounted for by phytoplankton photoacclimation (changes of chlorophyll-to-carbon ratios), the surface peak of phytoplankton growth rates suggests that the phytoplankton growth rate is not really limited by nutrient availability but could be light-limited. We developed a 1D model that couples ocean physics with two different kinds of ecosystem models (one species vs. two species of phytoplankton) built upon nutrient-phytoplankton-zooplankton-detritus (NPZD) plankton models. Model parameters were optimized by a Delayed Rejection Adaptive Monte-Carlo (DRAM) algorithm. Results suggest that the two-species model can better reproduce the vertical patterns of NPP. The implications are: 1) phytoplankton nutrient limitation may not be as severe as previously expected and light could play a more important role in controlling NPP in the oligotrophic open ocean; 2) phytoplankton diversity seems critical in faithfully reproducing NPP patterns.

Keywords: Primary production, Phytoplankton, community structure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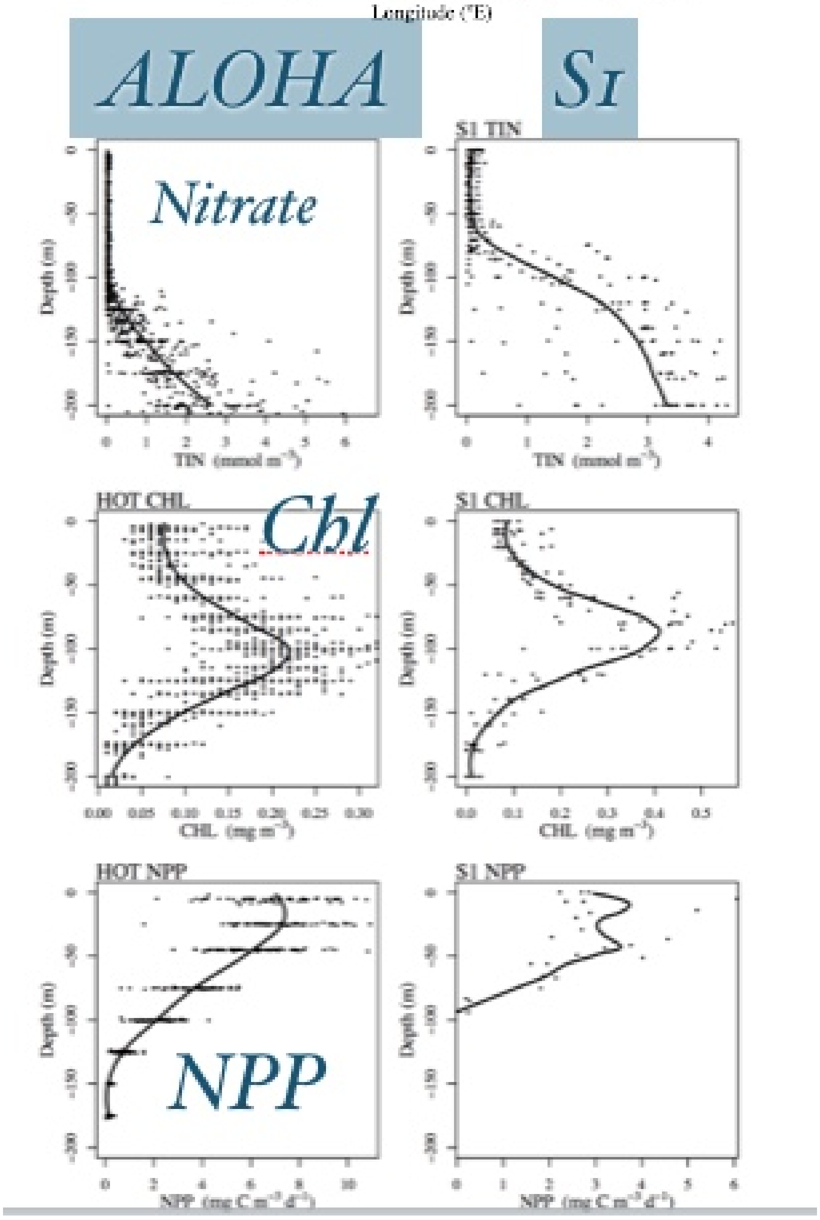
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Microscale spatial variability of plankton and new closure ecosystem models coupled with a 1D physical model

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Recent development of measurement technologies allows us to investigate microscale distributions of plankton. For instance, Doubell et al. (2009) employed the microstructure profiler TurboMAP-L equipped with a laser fluorescence probe and observed highly intermittent spatial variability of phytoplankton at a mm scale. The phytoplankton distributions acquired by the laser probe were patchier and more intermittent than those obtained concurrently by a conventional light emitting diode (LED) probe that resolves a cm scale. However, 1-m averaged profiles were consistent for both probes. This indicates that the intense fluorescence peaks are not noise signals but are due to highly concentrated phytoplankton aggregates. The results from high-resolution in situ observations demonstrate that microscale plankton communities and organic/inorganic particles play a vital role in ocean ecosystem dynamics. It has thus become urgent to develop a new ecosystem model which takes the observed microscale variability into account.

Mandal et al. (2014) developed a simple nutrient-phytoplankton (NP) ecosystem model by applying the closure approach, which decomposes each variable (N, P) into mean (N_0, P_0) and fluctuating component (N', P'). The NP closure ecosystem model consists of five variables: mean N_0 and P_0, variance $\langle N'^2 \rangle$ and $\langle P'^2 \rangle$, and covariance $\langle N'P' \rangle$, where angle brackets denote ensemble averaging. To evaluate the magnitude of fluctuating components in the ecosystem, Mandal et al. (2014) defined a non-dimensional parameter $\beta = B/A^2$, where $A = N_0 + P_0$ is the total mean and $B = \langle N'^2 \rangle + \langle P'^2 \rangle + 2\langle N'P' \rangle$ is the total variability. Mandal et al. (2014) performed dimensionless time-series simulations and found that the growth of P_0 was enhanced under high variability (high β) conditions. Subsequently, Priyadarshi et al. (2016) developed a new nutrient-phytoplankton-zooplankton (NPZ) closure model. The results of dimensionless time-series analyses showed that zooplankton biomass increased with increasing variability; on the other hand, phytoplankton biomass decreased. This suggests that trophic transfer in the food chain becomes more efficient under high variability conditions. However, these analyses excluded the effect of physical processes, for instance diurnal/seasonal variation of solar insolation, water movement, and stratification. To investigate the impact of microscale variability on ocean ecosystem dynamics, it is necessary to couple the closure ecosystem models with physical models.

We implemented the NPZ closure ecosystem model in a 1D water column physical model, General Ocean Turbulence Model (GOTM), using the same method as the physical-biological coupling by Mandal et al. (2016). GOTM is a public domain model (http://www.gotm.net) which is freely available to the community and reproduces reasonable seasonal cycle of stratification and vertical diffusion in the open ocean. The results of annual simulations showed that microscale variability led to the enhancement of Z_0 growth after the spring bloom of P_0. However, P_0 and Z_0 were rapidly depleted in spring when β is greater than or equal to 1 since Z_0 grazing was too fast under high variability conditions. Dynamics of Z_0 is sensitive to the covariance $\langle P'Z' \rangle$, implying that the combination of phytoplankton aggregates and zooplankton communities impacts ocean ecosystem dynamics. We will present the outcomes from this 1D mixed layer simulations.

Keywords: NPZ model, closure ecosystem model, microstructure, GOTM

Future Global Ocean Observing System –built on Requirements, promoting Alignment, delivering Relevant Information.

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Since the OceanObs’ 09 Conference, the ocean observing community has been improving coordination and collaboration amongst physical, biogeochemical and biology/ecosystem communities. Significant progress has been made through the introduction of the Global Ocean Observing System (GOOS) Framework for Ocean Observing in 2012. Societal and scientific requirements for sustained observations have been captured in Essential Ocean Variables (EOVs), many of which are also essential climate variables (ECVs, defined by the Global Climate Observing System (GCOS) reporting to the UNFCCC). Defined and emerging disciplinary EOVs are based on analysis of feasibility and impact, and how they deliver the needed data for scientific questions and societal requirements.

With advances in observing technology, and the definition of EOVs, clear opportunities exist to improve the coordinated planning and implementation of observing activities measuring across the three disciplines and all relevant temporal and spatial scales, eventually leading to truly fit-for-purpose observing system design.

GOOS works directly with several formal bodies programmatically connected to IOC-UNESCO, WMO as well as the WMO-IOC JCOMM to integrate ocean observation information into the GCOS Implementation Plan in support of the UNFCCC, the World Summit on Sustainable Development, the Group on Earth Observations, and other international and intergovernmental strategies.

In our opinion, a direct communication and coordination with regional communities such as JpGU is necessary to fully connect the opportunities arising on the decision and policy-making arena with technical developments occurring globally and regionally.

Integrating biogeochemical cycles across scales: A unified approach for regional predictions.

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It is recognized that even though climate models show significant skill in simulating both physics and biogeochemistry on global scales, they are not necessarily designed for regional studies. In the physical environment, significant effort has been devoted to downscaling techniques both in the atmosphere and the ocean. There are considerably less attempts at downscaling biogeochemistry. This is partly a consequence of the different models being used by the global and regional physical and biogeochemical communities. This disconnect leads to limited high-resolution regional projections of ecosystem dynamics. In this work, we present the recent development of a multi-scale coupled bio-physical model used for this purpose. The framework is based on the NOAA-GFDL earth system model and the regional ROMS circulation model. The same biogeochemical model, COBALT, has been implemented in both models for a consistent integration across scales. We present results from regional, high-resolution implementations in the California Current System and the northwest Atlantic. We show that improved representation of the physics is a critical step towards more skillful predictions of the ecosystem in coastal areas.

Keywords: Coupled biophysical models, Downscaling

Will Climate Change Result in Seasonal Mismatches between Phytoplankton Blooms and Fish Reproduction?

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One hypothesis explaining substantial interannual variability in fish recruitment (*i.e.*, the number of young fishes entering a fishery) is whether the timing of fish spawning matches seasonal plankton blooms that the fish’s larvae depend on for nutrition. Environmental processes controlling the seasonal timing (*i.e.*, phenology) of blooms often differ from those influencing fish spawning, which could cause these events to diverge under climate change with negative consequences for fisheries. We use an earth system model to examine the impact of the RCP8.5 climate-warming scenario on the future spawning time of two classes of fishes: “geographic spawners” whose spawning grounds are defined by fixed geographic features (*e.g.*, estuaries, reefs), and “environmental spawners” whose spawning grounds move responding to variations in environmental properties, such as temperature. Our model projects that by the century’s end spring and summer phytoplankton blooms will occur 16.5 days earlier on average at latitudes >40°N. The phenology of geographic spawners shifts at a rate twice as fast as phytoplankton, causing these fishes to spawn before the bloom across >85% of this region. “Extreme events” (*i.e.*, mismatches in timing >30 days that could lead to fish recruitment failure) increase 10-fold for geographic spawners in many areas. Seasonal mismatches between environmental spawners and phytoplankton were less widespread although sizable mismatches still emerged in some regions. This indicates that range shifts undertaken by environmental spawners may increase resiliency of fishes to climate change impacts associated with phenological mismatches, potentially buffering against declines in larval survival, recruitment, and fisheries.

Keywords: Earth System Model, phenology, trophic mismatch, phytoplankton bloom, fish spawning

Possible uncertainty in CMIP5 projections of low-oxygen water volume in the Eastern Tropical Pacific

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Using the results from nine Earth system models submitted to the Coupled Model Intercomparison Project Phase 5 (CMIP5), we identify the Eastern Tropical Pacific (ETP) as the region with the greatest uncertainty of future changes in oxygen-deficient ($< 30\,\mu$M) water volumes, since different models variously project both positive and negative changes in the oxygen-deficient volume and export flux there. We investigate the factors controlling future changes in oxygen-deficient volume in the ETP with global warming, using a single offline biogeochemical model. Oxygen budget analysis clarifies that the Equatorial Undercurrent (EUC) is the key mechanism controlling future variations in the oxygen-deficient volume in the ETP in our model. From the outputs of all of the CMIP5 models, we identify a significant negative relationship between changes in the EUC volume transport and the oxygen-deficient water volume from the present to the end of the 21st century, which indicates that the response of the EUC to global warming leads to one possible uncertainty in future projections of oxygen-deficient volume in the ETP.

Keywords: low-oxygen water volume, global warming, Eastern Equatorial Pacific

Estimation of sedimentary iron flux to the world ocean

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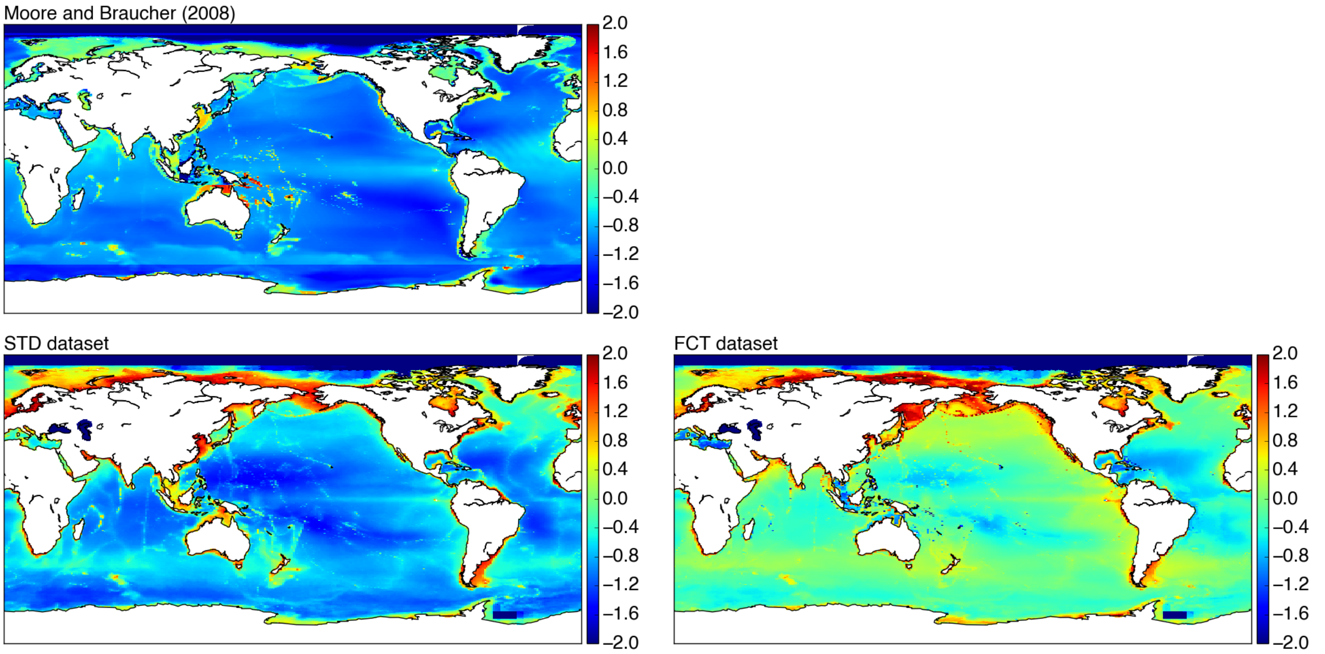
Iron is an important nutrient in marine biogeochemical cycles because it limits primary production in high-nutrient, low-chlorophyll areas. Iron cycle is implemented in the most marine biogeochemical cycle models used for future climate projection lead by IPCC. It has been revealed that the deposition of aerosols, release of iron from seabed sediments and hydrothermal vents are the major iron sources to the ocean. These exogenous iron inputs are considered in marine biogeochemical cycle models as the boundary conditions, but the magnitude and distribution of the fluxes are vary significantly among the models (Tagliabue et al., 2016). The sedimentary iron flux showed the largest dispersion among the exogenous inputs, it varies two-orders of magnitudes (0.6-196 Gmol/yr; Tagliabue et al., 2016), being a cause of the large discrepancy of simulated dissolved iron distributions among the models. Consequently, to construct a more precise sedimentary-iron flux dataset and standardize it are urgent need to reduce model uncertainty.

This study proposes new datasets of the sedimentary iron flux for the global ocean (Fig 1). We used formulae presented by Moore and Braucher (2008) where sedimentary iron flux is proportional to the particulate organic carbon (POC) flux reaching to the seabed sediment. This formulation is based on an empirical relationship observed in flux chamber data off the coast of California (Elrod et al., 2004). Moore and Braucher (2008) used the POC flux simulated in their model (BEC). In this study, we instead used the POC flux estimated from satellite data to prevent from two potential problems using the simulated POC flux: 1) coarse-resolution global models usually underestimate the POC flux in the coastal areas where the sedimentary iron fluxes are particularly large, and 2) using simulated POC flux is a cause of inter-model discrepancy of the sedimentary iron flux because the simulated POC fluxes are always different among the models. Our approach therefore can provide more proper sedimentary-iron estimate with model independent manner.

In addition to this standard dataset (hereafter STD dataset), we propose another dataset that is corrected from the STD dataset considering the bottom water properties. The reason of the proportionality between sedimentary iron and POC fluxes is considered that remineralization of organic matter in sediment consumes dissolved oxygen and reduces iron to more soluble Fe(II). The reduced iron is oxidized rapidly when it reaches to oxic bottom water, but the oxidation rates depend on bottom water properties such as temperature, salinity, dissolved oxygen and pH. We estimated the oxidation rates using an empirical relationship (Tagliabue et al., 2011) and the GLODAP v2 dataset (Lauvset et al., 2016 and Key et al., 2015). The obtained oxidation rates were then normalized by the value off the coast of California where the proportional constant between the sedimentary iron and POC fluxes is observed. The resultant non-dimension factors were multiplied to the STD dataset (hereafter FCT dataset).

Both the STD and FCT datasets showed larger sedimentary iron flux (200, 321 Gmol/yr in the global sum) than the previous estimates. The larger fluxes are attributed mainly to increase the fluxes in the shelf regions. The FCT dataset predicted larger fluxes in deep-sea sediments and shelf areas in high latitudes than the STD dataset reflecting slow oxidation rates due to low bottom-water temperatures. In addition to the magnitudes, the horizontal distributions are significantly altered from the fluxes estimated by Moore and Braucher (2008). The fluxes are increased mainly in the Pacific and Arctic Oceans where the shelf areas are extensive. Simulated results put these datasets into a marine biogeochemical cycle model will be presented in this talk.

Keywords: Iron, Sediment, Marine biogeochemical cycles



Roles for the ocean mesoscale on the supply of mass and tracers to the Northern Hemisphere subtropical gyres

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Lateral transport at the boundaries of the subtropical gyres plays a crucial role in providing the nutrients that fuel primary productivity, the heat that helps restratify the surface mixed layer, and the dissolved inorganic carbon (DIC) that influences air-sea carbon exchange. Mesoscale eddies are hypothesized to be an important component of these lateral transports; however, previous studies have not explicitly quantified the role played by these eddies. Here, we quantitatively assess the physical mechanisms that control the transport of heat, nutrients and carbon across the North Pacific and North Atlantic subtropical gyre boundaries using the eddy-rich ocean component of a climate model (GFDL's CM2.6) coupled to an idealized biogeochemical model (mini-BLING).

Our results suggest that lateral cross-subtropical gyre boundary transport supplies a substantial amount of heat, DIC, and nutrients, mainly across Gulf Stream and Kuroshio. Mass, heat, and DIC supply is mainly driven by the mean circulation, while mesoscale eddies oppose the mean, removing mass, heat and DIC from the gyres. Nutrient transport differs markedly from the other tracers, as nutrients are principally supplied to both subtropical gyres by mesoscale eddies. These lateral transports of heat, DIC, and nutrients all play a significant role in their respective subtropical gyre budget in both basins: Mean lateral transport supplies almost all DIC and heat into the subtropical gyres, with 37% (32%) of DIC and 21% (24%) of heat being removed from the North Pacific (North Atlantic) subtropical gyre by the eddy component of the lateral transport on an annual mean basis. The eddy lateral transport of heat is, on average, the same order of magnitude as the air-sea fluxes, implying its important role in subtropical ocean climate. Likewise, the lateral nutrient supply, combining the roles of both mean and eddy components, provides 77% of total nutrient supply in North Pacific and 86% in North Atlantic, which is approximately 1.5 times larger than a previous estimate by a coarse resolution model.

Surface nutrients in the North Pacific from ship-of-opportunity observation

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National Institute for Environmental Studies (NIES, Japan) and Institute of Ocean Sciences (IOS, Canada) has carried out ship of opportunity measurements of nutrients (phosphate, nitrate, and silicate) and partial pressure of CO_2 since late 1980s. Using the ship of opportunity data and others, seasonal to decadal variability of sea surface nutrients and dissolved inorganic carbon (DIC) in the North Pacific were clarified. Nutrient and DIC concentrations were high in the subarctic in winter and low in the subtropics. In the summer, substantial amount of nutrients remained unutilized in subarctic and the northern part of the subarctic-subtropical boundary region. In the subtropics, nutrients were almost entirely depleted throughout the year, while DIC concentrations showed a north-south gradient and significant seasonal change. Nutrients and DIC showed a large seasonal drawdown in the western subarctic region, while the drawdown in the eastern subarctic region was weaker, especially for silicate. The subarctic-subtropical boundary region also showed a large seasonal drawdown, which was most prominent for DIC and less obvious for nitrate and silicate. In the interannual time scale, the Pacific Decadal Oscillation was related to a nutrients and DIC seesaw pattern between the subarctic-subtropical boundary region and the Alaskan Gyre through the changes in horizontal advection, vertical mixing and biological production. When the North Pacific Gyre Oscillation was in the positive phase, nutrient concentrations in the subarctic were higher than the mean states. Trends of phosphate and silicate averaged over the North Pacific were negative, while nitrate trend was insignificant.

Keywords: phosphate, nitrate, silicate, PDO, NPGO, long-term trend

Biogeochemical impacts of isopycnal nitrate transport along the Kuroshio

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Recently the Kuroshio draws attentions as an important supply route of nutrient in the western North Pacific, although it has been generally recognized as a mere boundary between the oligotrophic subtropical waters to the south and the more productive coastal or subarctic waters to the north. The effective processes of the nutrient supply into the euphotic layer in the adjacent and downstream regions of the Kuroshio were reviewed on the basis of our recent in situ observations and retrospective analyses of historical observational and data-assmilated reanalysis datasets. The observation data revealed that the nutrient maximum was distributed along the jet on the isopycnal surface of 24.5-25.5sigma-theta in the whole region of the Kuroshio from the East China Sea to the Kuroshio Extension, and that the along-jet-maximum structure was detected only in spring, although the structure was analogous to the characteristic one well-known as the Nutrient Stream found in the Gulf Stream region. The concentration of the nutrient maximum gradually decreased along the jet toward the downstream region, implying that the high nutrient water was originated from the intermediate layer in the upstream and its adjacent regions. Isopycnal transport of nitrate along the jet was estimated at 800 kmolNs^{-1} by integrating from the layer of 27.5sigma-theta to the sea surface in the midstream region south of Japan, where the core of isopycnal downstream flux amounted to 10 mmolNm^{-2}s^{-1} on the surface of 26.0-26.5sigma-theta. The isopycnal transport plays the main role on the nutrient supply to the downstream, but on the way to the downstream, diapycnal upward flux due to turbulent diffusion whose net intensity amounts to O(10^{-6}) mmolNm^{-2}s^{-1} at the front supplies the nutrient effectively into the euphotic layer from the nutricline. Moreover lateral exchanges with the Slope or Shelf Waters due to both mesoscale and sub-mesoscale processes modifies the nutrient concentration in the Kuroshio jet, where the lateral flux due to horizontal diffusion was estimated at O(10^{-2}) mmolNm^{-2}s^{-1} at the front on the scale of O(10) km. The isopycnal surface at the nutricline depth in the upstream gradually shallows along the jet toward the downstream and finally reaches the winter mixed layer in the Kuroshio Extension to induce the nutrient supply into the euphotic layer. The nitrate flux due to the induction process can be estimated at O(10^{-5}) mmolNm^{-2}s^{-1}, some of which are transported eastward along the jet or recirculated to the subtropical region and the others are to the Kuroshio-Oyashio (K-O) interfrontal zone. The latter part suggests significant contribution of the isopycnal nutrient transport along the Kuroshio to the high productivity in the K-O zone.

Keywords: Kuroshio, isopycnal transport, Nutrient Stream, induction

Seasonal variations in nutrients and biogenic particles in the East China Sea and their exchange fluxes with adjacent seas

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Based on a three dimensional low-tropical ecosystem model, we revaluated the budgets of nutrients and biogenic particles (phytoplankton and detritus) in the East China Sea (ECS), a continental shelf sea with high productivity and affected by a large river (Changjiang) and a western boundary current (Kuroshio). After a careful comparison of model results with all available observation data, we calculated monthly standing stock of the nutrients and biogenic particles in the ECS and the fluxes of the nutrients and biogenic particles through the lateral and vertical interfaces of the ECS. As an improvement over previous nutrients budget calculations that treated the ECS as a one box, we divided the water column into two layers to represent the euphotic and aphotic layers. Our calculation shows a necessary for evaluating not only the horizontal fluxes of nutrients and biogenic particles into and out of the ECS through its lateral boundaries with adjacent seas but also the exchange fluxes of nutrients and biogenic particles between the euphotic and aphotic layers. Our calculation also reveals that the export of biogenic particles from the ECS to the Japan/East Sea is more than that from the ECS to the Kuroshio region and the export pathway of biogenic particles from the ECS to the Kuroshio region is through the middle layer of the shelf slope of the ECS, not the previously reported bottom layer.

Keywords: low-tropical ecosystem model, East China Sea, Kuroshio, Changjiang, Japan/East Sea

Biogeochemical implications of potential future changes in shelf sea circulation

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Simulations of the NEMO-ERSEM Atlantic Margin Model (AMM7) of the NW European continental shelf driven by climate models out to 2100 have shown the potential for substantial changes to the ocean-shelf exchange and shelf scale circulation, drawing on simulations from the ROAM and RECICLE projects. In one realisation of future conditions the inflows into the North Sea through the Fair Isle channel and east of Shetland are found to substantially decrease, and the Shetland shelf current largely by-passes the North Sea. This significantly reduces the cyclonic North Sea circulation and shifts the balance between oceanic and terrestrial influence in this region, seen by a substantial decrease in salinity. In this presentation we consider what the biogeochemical implications of this might be. Using output from the ERSEM model in this simulation, we explore the spatial distribution of these changes and consequent changes in nutrient ratios, and other factors in play that may mitigate or aggravate this view (Holt et al 2016). We use the driving ¼° global NEMO model (Yool et al 2015) to explore whether other semi-enclosed shelf sea basins around the world might show similar behaviour under this future scenario. The long-term nutrient budgets in shelf-seas are set by the relative balance of oceanic and riverine inputs, augmented by atmospheric inputs and modulated by exchanges between benthic and pelagic systems. A simple mixing box estimate suggests that in the North Sea case, this change in circulation leads to an increase in nitrate by 15% and the flushing time increases from 1.8 years to 2.5 years; this potentially mitigates against the effects of a reduction in oceanic nutrient concentrations being advected on-shelf, which have previously been identified (Holt et al 2012).

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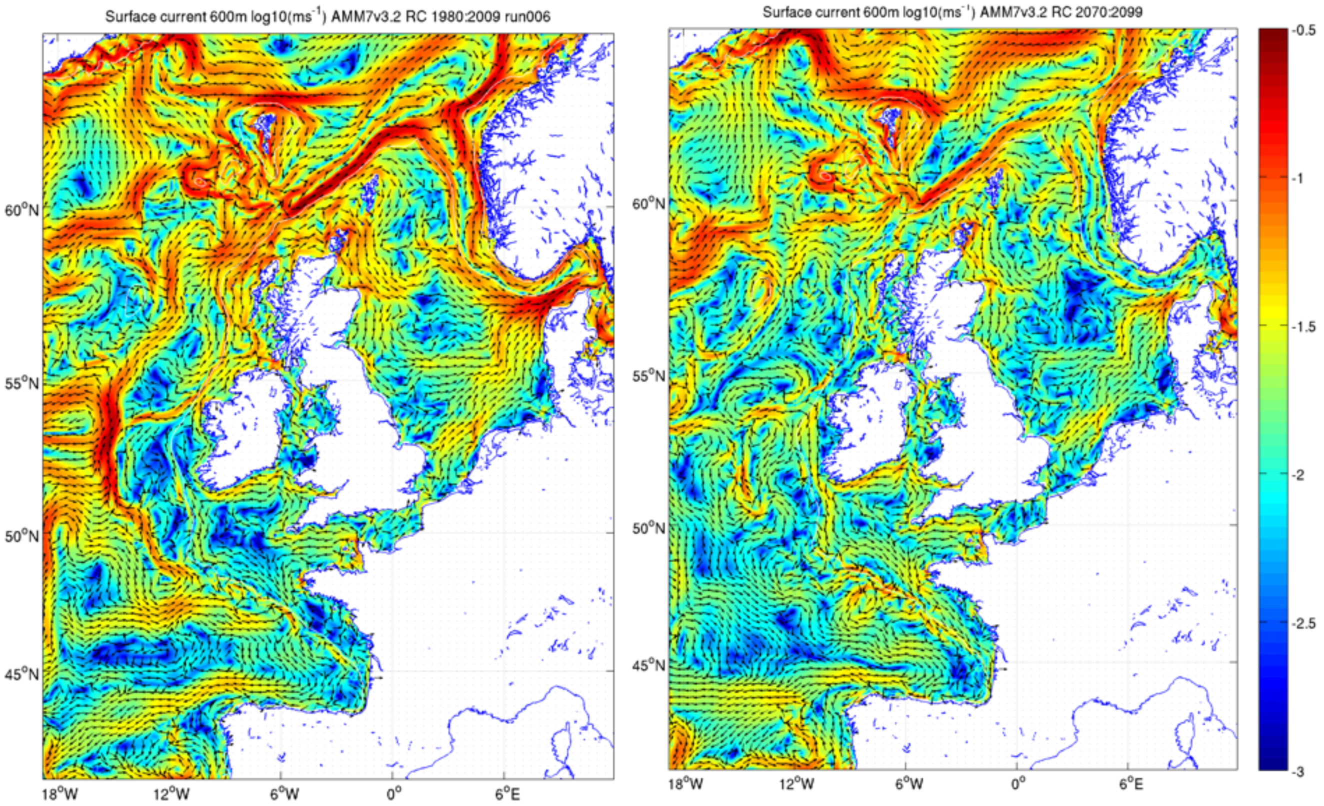
Keywords: Climate impacts, Shelf sea ecosystems, Ocean shelf coupling


Surface current 600m log10(ms^{-1}) AMM7v3.2 RC 1980:2009 run006
Surface current 600m log10(ms^{-1}) AMM7v3.2 RC 2070:2099
60°N
55°N
50°N
45°N
18°W
12°W
6°W
0°
6°E
-0.5
-1
-1.5
-2
-2.5
-3

A numerical model for separating nutrients with different origins in the ecosystem of the East China Sea

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The nutrients in the East China Sea (ECS) come from different sources, such as Kuroshio, Taiwan Strait, rivers, and atmosphere. To evaluate the roles of multi-source nutrients in the primary production over the continental shelf of the ECS, a tracking technique was applied to all the state variables (dissolved inorganic nitrogen (DIN), two types of phytoplankton (diatoms and flagellates), and detritus) in a low-trophic ecosystem model. This tracking method is able to separate the nutrients and chlorophyll *a* with different sources in a realistic simulation designed for reproducing the temporal and spatial variations of nutrients and chlorophyll *a* in the ECS. The distributions of the DIN from different sources depend closely on the currents and change seasonally. The DIN from Changjiang River concentrates in the inner shelf in winter but heads to the Tsushima Strait along with the diluted water in summer. In the upper layer of the middle and outer shelves in winter, the DIN mainly comes from the Kuroshio; in the lower layers from middle shelf to outer shelf, the DIN from the Kuroshio plays a dominant role all the year round, especially in summer. The Taiwan Strait currents are strong and shift a little offshore in summer, resulting in the distribution of the DIN from the Taiwan Strait in the surface layer over the middle and outer shelves in summer. The high concentration of the DIN from atmosphere mainly locates at the Bohai Sea and the Yellow Sea. The DIN input flux of the Kuroshio and the corresponding net primary production (NPP) are highest among all the sources. However, the ratio of the NPP to the input flux for each source of nutrient indicates that the nutrient with Kuroshio source is the least efficient while that with the river source is the most efficient.