Bottom-upとTop-down制御による海洋食物連鎖の平衡解
Equilibrium Solutions for Marine Food-chain to Bottom-up and Top-down Controls

*磯田 豊[1]
*Yutaka Isoda[1]

1. 北海道大学大学院水産科学研究院
1. Hokkaido University

1．はじめに

古海洋は専門外なので間違っているかもしれないが，古海洋研究では海底堆積物中の微化石や魚の鱗などの生物指標を用いることが多いように思う。また，対象とする時間スケールが千年～万年単位の超長周期なので，下記に紹介する食物連鎖を考慮した生物指標の量的大小（変動）の議論に，どれだけ意味があるかはわからない。ただ，古代生物であっても子孫を生み続けて，進化して現在の海洋生態系まで繋がっているので，「食う-食われる」の捕食被食関係はあったはずと思う。そう願って，多段階（ここでは4段階）の食物連鎖を簡単な数理モデルで表現し，その平衡解を眺めながら，超長周期（古海洋時間スケール）の生態系応答を考えてみたい。

2．食物連鎖が4段階（4-Level）のVolteraa式

Nは栄養塩（窒素など），Pは植物プランクトン，Zは動物プランクトン，Fは魚を示す各Stock量とし，単純なFlow項とLoss項で表現されるVolterra式は下記となる（Fig.1参照）。

$$dN/dt = -(\alpha_p P)\, N + (N_0 - N)\, \theta\,[t-n]/t_a \quad (n=1,2\cdot\cdot年) \quad (1)$$

$$dP/dt = -(\alpha_z Z)\, P + (\alpha_p N)\, P - \beta_p P \quad (2)$$

$$dZ/dt = -(\alpha_f F)\, Z + (\alpha_z P)\, Z - \beta_z Z \quad (3)$$

$$dF/dt = (\alpha_f Z)\, F - \beta_f F \quad (4)$$

ここで，αはFlow（同化）率，βはLoss（死亡）率を示し，$\theta\,[t-n]/t_a$は年1回の春季ブルームを表現する関数である。

3．4-Level食物連鎖の平衡解

Flow率を簡単化のため同値（$\alpha=\alpha_p=\alpha_z=\alpha_f$），$\theta=1$を仮定し，各Levelの平衡（定常）解N*，P*，Z*，F*を求めると

Level-1　$N^* = (\beta_f + \beta_p)/\alpha$

Level-2　$P^* = (N_0/(\beta_f + \beta_p)\text{-}1/\alpha)/t_a$

Level-3　$Z^* = \beta_f/\alpha$

Level-4　$F^* = P^* - \beta_z/\alpha$

となる。これらの平衡解は興味深い性質をもつ。まず，全てのLevelのStockは最上位の捕食者（F）のLoss率β_fに依存する。すなわち，FのLoss率β_fが増加/減少すると，奇数番であるLevel-1（N*）と3（Z*）のStockは増加/減少するのに対し，偶数番であるLevel-2（P*）と4（F*）のStockは逆に減少/増加する。さらに，偶数番のLevel-2（P*）と4（F*）のみが，最下位の栄養塩N_0の関数である。すなわち，偶数番LevelのStockのみ，N_0が増加/減少すると増加/減少する。このように，偶数番と奇数番のLevelで異なった応答を示す性質は，食物連鎖のLevel数を変えても同じである。

この平衡解を用いて，近似的に超長周期の変動に対する生態系応答を推測してみよう。Top-down制御を最上位捕食者（F）のLoss率β_fの変動と考えれば，[N,Z]と[P,F]はお互い逆位相の変動を示す。一方，Bottom-up制御を栄養塩供給量N_0の変動と考えれば，[P,F]はNに同期した変動として現れるが，[Z]の変動がどうなるかはわからない。それゆえ，海洋生態系がTop-downとBottom-upの制御，いずれが支配的な状態なのかの診断は，Stockデータが示す[Z]と[N,P,F]の位相関係にある。講演では現代の北太平洋生態系を例に，どちらの制御にあるのかの診断を試みる。古海洋研究において，研究対象とした生物指標が古代食物連鎖のどの食物段階（Level）に位置しているかに依存して，環境変動と生物指標変動の位相関係が違ってみえるかもしれない？と夢想する。

キーワード：Bottom-up制御、Top-down制御、海洋食物連鎖、Volteraa式
Keywords: Bottom-up control, Top-down control, Marine food-chain, Volteraa equation

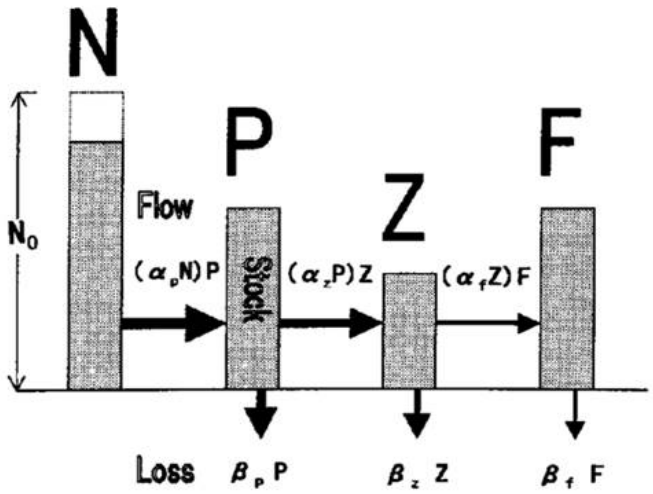

Fig. 1. Diagram of the dynamics of our food-chain model with four stock levels: N (nutrient), P (phytoplankton), Z (zooplankton), and F (fish).

数値シミュレーションを用いた過去1万年間の東京湾の潮汐変化推定
Tidal changes in the Tokyo Bay during the last 10,000 years estimated from a numerical model

*上原 克人[1]
*Katsuto Uehara[1]

1. 九州大学
1. Kyushu University

１．はじめに

潮汐や潮流の影響が相対的に大きい沿岸域では、地質記録から古海水準や物理・生物環境を復元する上で、過去の潮汐に関する知見は大切な情報である。数値モデルを使った沿岸域古潮汐復元の試みは、カナダ・ファンディ湾を対象としたScott and Greenberg (1983)など、海外では多くの実施例があるが、日本では一次元モデルを使った大阪湾に関するTojo et al.(1999)以外にない。本研究では、東京湾における過去1万年間の古潮汐変動を二次元数値モデルにより推定した。

２．東京湾の地形変化

潮汐変化をもたらす最大の要因は、地形変化(水深と湾長)である。東京湾では、東木(1926)による古海岸線復元を端緒に地質情報に基づく古環境復元が数多く行われ、不十分ながら日本で最も古地形情報が得られている内湾の一つである。特にこの１０年間、湾奥の東京低地・中川低地では高密度のボーリングコア情報を利用した詳細な古地形の復元が進められている(田辺、2013)。過去の知見によれば、東京湾は海面が低かった時代には干出していたが、約1万年前頃からの海面上昇に伴って海水が流入するとともに湾域が広がり、縄文海進期と呼ばれる約６～７千年前には海岸線が現在よりも陸側に７０ｋｍ前後後退していたと考えられている。

３．手法

本研究では、既存の地質解析の成果を利用して１万年前から４千年前までの古地形を千年ごとに復元し、二次元潮汐モデルと組み合わせることで、古潮汐を推定した。駆動源となる外洋潮汐は、全球古潮汐モデル(Uehara et al., 2006など)にて大きく変化していなかったことから、現世の値を用いた。

４．結果

数値計算を行った結果、東京湾の潮差は湾域の拡大とともに増大し、縄文海進期には湾奥の潮差が現在よりも５２～９３％増大していたと推定された。この値は、線形で摩擦を考慮しない解析モデルによる藤本(1990)の結果(現世の3倍の潮差)よりかなり小さいが、摩擦や詳細な地形を取り入れた分、今回の推計の方がより現実に近いと考えられる。さらに内湾域のタイダル・プリズムの増加に伴い、湾口の潮流流速の増加が認められた。潮流による海水交換の増加が、内湾の環境変化をもたらしていた可能性がある。強い潮流は、海面上昇が始まった時期にも見られ、湾内外に存在する完新世基底礫層の形成と関係していた可能性がある。

５．おわりに

物理的手法に基づく本研究結果は古地形や海水準など地質学的知見に大きく依存している一方、侵食のため地層が残っていない場所に関する情報など、地質解析の精度向上に還元できる部分も多々あると思われ、両者を組み合わせることで古環境復元の一層の精度向上に結びつくことが期待される。

キーワード：完新世、古潮汐、数値シミュレーション、奥東京湾、海水準変動
Keywords: Holocene, paleotides, numerical simulation, Oku-tokyo Bay, Sea-level change

Possible oceanic signals of the 18.6-year period modulation of tide-induced vertical mixing

*長船 哲史[1]
*Satoshi Osafune[1]

1. 国立研究開発法人海洋研究開発機構
1. Japan Agency for Marine-Earth Science and Technology

Bi-decadal variability is one of the prominent features of the decadal to multi-decadal ocean and climate variability in the North Pacific. This has received considerable attention, because this is seen in many societally important variables such as air temperature, precipitation, and even fishery resources. However, while several possible mechanisms underlying this variability have been proposed, it has not been fully understood. The 18.6-year nodal tidal cycle related to the precession of the moon’ s ascending node is a possible one. It is known that the diurnal tides induce strong vertical mixing around steep topographies like sills in the Kuril Straits and the Aleutian Passes, and this strong mixing is thought to play important roles in water-mass modification. The 18.6-year cycle largely modulates the amplitudes of the major diurnal tidal constituents by 11% and 19% for K_1 and O_1, respectively. Thus, it is hypothesized that the modulation of mixing contributes to the bi-decadal variability in water-masses in the North Pacific and its marginal seas. Using the historical ocean observation data, I found various bi-decadal variations downstream of the strong mixing regions, which can be explained qualitatively by the modulation of vertical mixing, although it is difficult to prove whether those are really the 18.6-year period signals by using only the limited observation data.

キーワード：20年変動、潮汐18.6年振動、潮汐鉛直混合
Keywords: bidecadal variability, 18.6-year nodal tidal cycle, tide-induced vertical mixing

海洋プランクトン（放散虫）の化石に記録された完新世における日本海固有水の変化

Holocene changes of the Japan Sea Proper Water (JSPW) inferred from marine plankton (radiolarian) fossil records

*板木 拓也[1]、池原 研[1]
*Takuya Itaki[1], Ken Ikehara[1]

1. 産業技術総合研究所
1. Geological Survey of Japan, AIST

The Sea of Japan has its own deep-circulation system, with its deeper parts occupied by cold and highly oxygenated water formed by winter convection in the northwestern part of the sea. According to recent observations, such deep convection has been weakened with the global warming. How was in the past warming before the historical period? For example, it is well known the warmer climate during the Jomon period (ca. 7,300 years ago) in the mid-Holocene. Here, we will discuss about the deep-circulation changes in the Japan Sea during the past 12,000 years (Holocene) based on marine plankton (radiolarian) fossil records.

Radiolarians are planktonic Protozoans widely distributed in the world ocean, and their skeletons composed of opal are preserved in marine sediments. Many radiolarian species are restricted to discrete depth intervals and the depths at which they dwell are closely related to the vertical water structure. As a result, radiolarian fossils prove to be useful indicators not only in the reconstruction of the surface water conditions, but also for the conditions of the water masses at intermediate and deeper depths. In the Sea of Japan, investigations based on plankton tows and surface sediments revealed that *Cycladophora davisiana* occurs in a depth interval between 1,000 m and 2,000 m (deep layer of JSPW = Japan Sea Proper Water), and *Actinomma boreale* group in depths below 2,000 m (bottom layer of JSPW).

The study of six sediment cores located in water depths ranging from 300 to 3,600 m show that the radiolarian assemblages have varied during Holocene, indicating changes in water-ventilation strength in this marginal sea. Bottom-water ventilation has been dependent on high-salinity inflow through the Tsushima Strait in the south and winter cooling in the northwestern part of the Sea of Japan. Deep water was being actively formed in the early Holocene. This bottom-water formation has resulted in relatively constant water composition since 9 cal ka BP, with the overall increase in high-salinity oceanic-water inflow, although the latter decreased transiently from 7,000 to 5,000 years ago in concert with climatic warming.

キーワード：古海洋学、微化石、水塊構造
Keywords: Paleoceanography, Microfissil, water structure

日本海における古海洋環境復元と物理モデルのコラボレーション
Collaboration study of paleoceanography and physical model in the Japan Sea

*佐川 拓也[1]、郭 新宇[2]
*Takuya Sagawa[1], Xinyu Guo[2]

1. 金沢大学理工研究域、2. 愛媛大学沿岸環境科学研究センター
1. Institute of Science and Engineering, Kanazawa University, 2. Center for Marine Environmental Studies, Ehime University

日本海は隣接する海域と繋がる海峡の水深が浅い縁辺海であるため，過去の海水準変動に強く影響を受けてきた．約2万年前の最終氷期最盛期（LGM）には大陸氷床が大きく発達し，海水準が現在よりも約130 m低かった．これは現在の対馬海峡や津軽海峡の水深とほぼ同程度であるため，当時の日本海は孤立した状態にあり対馬暖流は流入していなかったと考えられている．その後，氷期から後氷期にかけて起こった大陸氷床の融解によって，海水準は徐々に上昇するが，古生物学的記録によるとまず最初に日本海に流入したのは親潮であり，その後対馬暖流の流入が続いたことが示唆されている．現在の対馬暖流は対馬海峡側と津軽海峡側の海面差によって駆動されているが，全球的な海水準の変化が日本海の海流系をどのように変化させてきたのか海洋物理学的な見地から迫った例は少ない．堆積物コアに基づく古海洋学研究は，ある地点における時系列データを得意とする一方で，面的な広がりを議論するには多大な労力と様々な制約ゆえに限界がある．他方，物理モデルは計算機資源の制約もあり数万年に及んだ時間解像度の高い情報を得るのは難しいが，面的な海流系のシミュレーションを得意とする．こういった両者の特徴を上手く生かし補い合うことで新たな知見が得られることを期待する．本講演では，上述した問題意識の元に期待される古海洋学と海洋物理学のコラボレーションについて構想を紹介する．

キーワード：日本海、古海洋学、海洋物理学
Keywords: Japan Sea, Paleoceanography, Physical Ocenography

Reconstruction of vertical temperature structure in the East China Sea to better understand the past Kuroshio variability

*Yoshimi Kubota[1], Katsunori Kimoto[2], Ryuji Tada[3]

1. National Museum of Nature and Science, 2. Japan Agency for Marine-Earth Science and Technology, 3. University of Tokyo

The East China Sea (ECS) is a marginal sea, located in western edge of the Pacific and the Kuroshio is one of the major current systems in the ECS and has a crucial impact on water properties in the ECS (Chen et al., 2010; Guo et al., 2012). Because the position of the Kuroshio in the ECS is relatively stable (standard deviation is ~10 km) compared with the outside ECS (Andres et al., 2008), it is suitable to investigate long-term variations in the Kuroshio without the consideration of meandering of the main axis. However, there has been ongoing debate about the variability of the Kuroshio in the past in the East China Sea. One argument is, like the Ryukyu Current today, the Kuroshio main axis migrated to be outside of the Okinawa Trough during the last glacial maximum (LGM)(e.g., Ujiié et al., 1991; Ujiié and Ujiié, 1999; Diekmann et al., 2008). Another argument is that the Kuroshio main axis remained located in the Okinawa Trough even at the lowest sea level stand (e.g., Kawahata and Ohshima, 2004; Lee et al., 2013). Based on a comparison of planktic foraminifera assemblages inside and outside the Okinawa Trough, Ujiie et al. (2003) advocated “outside Okinawa Trough”. Their comparison revealed the appearance of cold water species inside the Okinawa Trough during LGM, despite only minimal variation in assemblage-derived sea surface temperature (SST) outside the Okinawa Trough. However, a recent study based on comparison of Mg/Ca-derived SST records demonstrated that there was no significant difference in SST between inside and outside the Okinawa Trough, suggesting the entrance of the Kuroshio inside the Okinawa Trough during the LGM (Lee et al., 2013). Although there are many studies focusing on reconstruction of surface hydrology in the Okinawa Trough since the MIS 3 or LGM using planktic foraminifera assemblages (Li et al., 2001; Ujiie et al., 2003; Xu and Oda, 1999) and alkenon-derived SST (Ijiri et al., 2005; Yu et al., 2009), and Mg/Ca-based SST (Chen et al., 2010; Kubota et al., 2010; Sun et al., 2005), information concerning water properties at subsurface and intermediate depth is sparse, which is important as variations in the Kuroshio velocity and transport have a greater impact on temperature and salinities at subsurface and intermediate depths rather than those at surface (Oka and Kawabe, 1998). In this study, we reveal temperature structure in the Okinawa Trough since the late MIS 3 and discuss how we understand the Kuroshio variability in the past.

Keywords: Kuroshio , East China Sea , Last Glacial period

堆積物記録に基づく瀬戸内海の過去150年にわたる低次生産量の変動ー外洋・陸起源の栄養塩はどんな影響を与えてきたかー

Temporal variations of productivity at low trophic levels over the past 150 years in the western Seto Inland Sea, Japan, revealed by sedimentary records

*槻木 玲美[1]、加 三千宣[2]、谷 幸則[3]、郭 新宇[2]、大森 浩二[4]、武岡 英隆[2]
*Narumi Tsugeki[1], Michinobu Kuwae[2], Yukinori Tani[3], Xinyu GUO [2], Koji Omori[4], Hidetaka Takeoka[2]

1. 松山大学 法学部、2. 愛媛大学　沿岸環境科学研究センター、3. 静岡県立大学　食品栄養科学部環境生命科学科、4. 愛媛大学 社会共創学部
1. Law Faculty, Matsuyama University, 2. CMES, Ehime University, 3. Department of Environmental and Life Sciences, School of Food and Nutritional Sciences, University of Shizuoka, 4. Faculty of collaborative Regional Innovation, Ehime University

We examined fossil pigments in a ^{210}Pb-dated sediment core to document the temporal variations in phytoplankton biomass over the past 150 years in a semienclosed bay, Beppu Bay, in the western Seto Inland Sea, Japan. The flux of fossil pigments was used as an index of phytoplankton biomass, which we reconstructed after removing the effect of post-burial degradation on the concentrations of fossil pigments.
The flux doubled from the 1960s to the early 1970s, decreased or remained stable in the early 1980s, and increased again from the late 1980s to the early 1990s. The first increase in phytoplankton biomass during the 1960s was likely caused by eutrophication due to an increase in terrestrial nutrient fluxes from watersheds. The decreasing phytoplankton biomass in the early 1980s was likely related to the establishment of a sewage treatment system that reduced the terrestrial nutrient fluxes to the sea. However, the terrestrial nutrient fluxes could not explain the second increase from the late 1980s to the early 1990s. Intensification of the influx of nutrients from the shelf slope to the sea was likely the cause of the second increase in phytoplankton biomass. This is supported by the inverse relationship between phytoplankton biomass and sea level at the shelf slope, the latter being an index of the intensity of the influx of oceanic nutrients from the shelf slope to the sea. The supply of oceanic nutrients may be therefore a critical factor in the determination of primary production in the western Seto Inland Sea.

キーワード：基礎生産、色素、瀬戸内海、黒潮、古海洋学、富栄養化
Keywords: Primary production, fossil pigment, Seto Inland Sea, Kuroshio current, Palaeoceanography, Eutrophication

Evidence for multiple redox zones in early Cambrian ocean

*Zihu Zhang[1,2], Meng Cheng[1], Chao Li[1,2]

1. School of Geosciences, China University of Geosciences Wuhan, 2. State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences

Ocean redox state is basically controlled by the balance between oxidizers and reductants. In theory, in addition to conventional oxygen and sulfate, Mn-Fe oxides and nitrate can serve as the oxidizer, whose reductions have been hypothesized to have generated manganous-ferruginous and nitrogenous zones between oxic and sulfidic zones in a highly stratified ocean of early Earth (>520 Ma; Li et al., 2015). To test this hypothesis, we conducted a high-resolution Fe-S-C-N and trace-element geochemical study of the early Cambrian Qingxi Formation in a deep-water setting at Silikou, Guangxi Province, South China. Integrated Fe-Mo-S-C-N data demonstrate an overall marine redox transition at Silikou from euxinic to oxic conditions up section, which is consistent with the gradual oxygenation of early Cambrian ocean observed widely in South China (Jin et al., 2016). However, our data also clearly reveal the developments of manganous-ferruginous and nitrogenous conditions during the transition as suggested by higher sedimentary Mo concentrations relative to U due to the adsorption to Mn-Fe oxides and subsequent reductions(i.e., the activity of Mn-Fe shuttle) and the abrupt increase of the organic N isotope from +2 ‰ to +5 ‰. The occurrence of these redox zones reflects the successive use of oxygen, nitrate, Mn-Fe oxides and sulfate as the oxidizers in early Cambrian oceans. Thus our study for first time provides direct evidence for the existence of these hypothesized redox zones in early Earth’ s oceans, which is of significance to our understanding of elemental biogeochemical cycles in early Earth’ s oceans and their impacts on biological evolutions.

References

Chao Li, Meng Cheng, Thomas J. Algeo, ShuchengXie. A theoretical prediction of chemical zonation in early oceans (>520 Ma). Science China Earth Sciences, 2015, 58(11): 1901-1909.

Chengsheng Jin, Chao Li, Thomas J. Algeo, Noah J. Planavsky,Hao Cui,Xinglian Yang,Yuanlong Zhao,Xingliang Zhang,ShuchengXie. A highly redox-heterogeneous ocean in South China during the early Cambrian (~529-514 Ma): Implications for biota-environment co-evolution, Earth and Planetary Science Letters, 2016, 441:38-51.

Keywords: Early Cambrian, Redox Condition, Early Animals, Oceanic Stratification

Chukchi and Bering Sea shelves contribution to Mn enrichment in the Arctic deep basin

*Liming Ye[1], Yeping Bian[1], Xiaoguo Yu[1]

1. Second Institute of Oceanography. SOA

A key role of the Siberian Arctic shelves has been suggested to play in the enrichment of Mn over all Arctic deep basins. On the orbital timescale, Mn records from the Alpha Ridge core 08B85-D displayed a close correlation to the Relative Sea Level changes on the independent age model. A threshold of -60 m sea level seems to be able to shift the Mn transportation from shelves to deep basins. This phenomenon in the core records was supported to some extent by the Mn distributions in the surface sediments with extremely low values over the Chukchi Sea and Bering Sea shelves and with relatively high values over the areas deeper than 60 m water depth. Another independent proxy Ce anomaly also shown the similar distributions as the Mn both in the core and the surface sediments, and suggested that the main transportation of Mn might occurred at the Chukchi Sea and Bering Sea shelves, rather than the Eastern Siberian Sea and Laptev Sea shelves. Especially the Contributions from the Bering Sea shelf should be considered to account for the Mn enrichment in the Arctic deep basins.

Keywords: Mn enrichment, Chukchi Sea shelf, Bering Sea shelf, Ce anomaly

Capturing extreme river runoff events from oceanic sediment distribution

*Shinichiro Kida[1], Yusuke Okazaki[2], Jon Woodruff[3]

1. Research Institute for Applied Mechanics, Kyushu University, 2. Department of Earth and Planetary Sciences, Kyushu University, 3. Department of Geosciences, University of Massachusetts - Amherst

A significant amount of the freshwater discharges around Japan occurs through extreme weather events. Capturing the event in the ocean, however, has been observationally difficult because of the strong currents and its random occurrence. Moreover, the low salinity signal often disappears after a few days since the majority of the rivers in Japan are directly connected to the open ocean and thus is strongly affected by its circulation. Regional-scale numerical oceanic models are becoming capable of resolving the dynamics of freshwater discharges but we have so far lacked a tool to test them from observations. We will introduce an observational project based on the Ariake Sea that aims to investigate the dynamics of the extreme freshwater discharges from oceanic sediments. The discharge following the Kumamoto Earthquake is likely associated with sediments that entered the rivers through the various landslides and thus contain a detectable record compared to previous years. The Ariake Sea is one of the few estuaries that is large to capture the discharge signal and not directed altered by the open oceanic circulation.

Keywords: river runoff, sediment, earthquake

完新世の気候変動に対する北西太平洋のイワシ類の応答
Response of Japanese sardine and anchovy abundances to orbitally driven climate changes during the Holocene

*加 三千宣[1]、山本 正伸[2]、竹村 恵二[3]、池原 研[4]、山田 圭太郎[3]、石下 浩平[5]、高松 裕子[5]、杉本 隆成
*Michinobu Kuwae[1], Masanobu Yamamoto[2], Keiji Takemura[3], Ken Ikehara[4], Keitaro Yamada[3], Kohei Ishishita[5], Yuko Takamatsu[5], Takashige Augimoto

1. 愛媛大学沿岸環境科学研究センター、2. 北海道大学大学院地球環境科学研究院、3. 京都大学大学院理学研究科、4. 産業技術総合研究所地質情報研究部門、5. 愛媛大学理学部
1. Center for Marine Environmental Studies, Ehime University, 2. Faculty of Environmental Earth Science, Hokkaido University, 3. Institute for Geothermal Sciences, Kyoto University,, 4. Research Institute of Geology and Geoinformation, Geological Survey of Japan, 5. Faculty of Science, Ehime University

完新世の気候変動に対して、浮魚類はどのように応答してきたか？これを知ることは、長期的な温度変化に対する浮魚類の応答について貴重な情報をもたらすかもしれない。世界で最も漁獲されるイワシ類を対象に、完新世における個体数の長期変動を魚鱗堆積量によって明らかにした。その結果、日本マイワシの魚鱗堆積量は7000年前から3500年前に増加トレンド、3500年前から現在まで減少トレンドを示した。カタクチイワシは3500年前以前は魚鱗堆積量は少なく、それ以降徐々に増加し、マイワシとカタクチイワシの間で逆のトレンドを示した。マイワシとカタクチイワシの成長速度は、それぞれの最適水温16℃と22℃のユニモーダルな水温応答を示すことが報告されており、最適水温より数℃の高水温あるいは低水温による成長速度の低下が再生産を悪化させ、マイワシとカタクチイワシの個体数の劇的な資源崩壊や魚種交替を引き起こす。これを'optimal growth temperature'仮説(Takasuka et al., 2007)という。実際、1980年代後半以降太平洋十年規模振動に代表される気候変動によって生じる水温変動によってマイワシ個体数が約90分の1にまで低下し、カタクチイワシへの魚種交替が起こったことが知られている。

この仮説は、完新世の気候変動においても魚鱗記録で見られるマイワシ・カタクチイワシの長期トレンドを説明できるだろうか。20世紀後半のマイワシ増加期における産卵場（日本南岸）の水温は17℃程度で、最適水温よりもやや高い水温であり、マイワシレジームにおける1℃の水温低下はさらに仔魚の生残率が高くなることが期待される。ミランコビッチサイクルに伴う日射量強制あるいは日射量・温室効果ガス両方の放射強制を与えたモデル計算(Lorenz et al., 2006; Ohgaito et al., 2013)によると、仔魚が分布する黒潮続流域の海面水温は、冬季の推定で過去6000年間で0.7℃前後の増加トレンドを示しており、6千年前にはマイワシレジーム時の水温は最適水温に近かったことになる。したがって、過去6000年間、水温応答特性が変化しないと仮定すれば、個体数は6000年の間減少トレンドを示すはずだが、実際は3500年前までは増加トレンドを示し、その後減少トレンドを示している。この矛盾について幾つかの原因が考えられが、最も有力な原因の一つは、モデル計算における粗い空間解像度により、仔魚の生残にとって最も重要な黒潮続流の流軸とその北+0.5˚の狭い範囲の水温の低下を過小評価している可能性が考えられる。1980年代のマイワシレジームでは17℃前後であったが、3500年前で今より1℃低下したとすれば現在よりも高い個体数を説明できる。また、6000年前に今より約2℃低下したとすれば、最適水温をさらに1℃下回るので、成長速度低下によってこの時の低い個体数を説明できる。一方カタクチイワシは現在のカタクチイワシレジームでは最適水温の22℃よりやや低い水温環境であるが、過去の温度の低下は成長速度の低下をもたらし、個体数を減少させる原因となったと考えれば、3500年前以降からの増加トレンドを説明できる。すなわち、どちらの長期トレンドも'optimal growth temperature'仮説によって説明できることになる。いずれにしても、マイワシやカタクチイワシに見られる長期トレンドの原因は、続流域の海面水温を決定する大気海洋過程の日射量変動に対する応答を高精度で解明することによって明らかになると考えられる。今後の海洋学と古海洋学の連携を期待したい。

キーワード：マイワシとカタクチイワシ、気候変動、完新世、北西太平洋

Keywords: Japanese sardine and Japanese anchovy, climate change, Holocene, Northeast Pacific

Multiple equilibria and overturning variability of the Aegean-Adriatic Seas

*Yael Amitai[1,2], Yosef Ashkenazy[2], Hezi Gildor[1]

1. The Hebrew Univ., 2. Ben-Gurion Univ., BIDR

The Eastern Mediterranean Transient (EMT) –a transition and amplification of the Eastern Mediterranean Sea deep water source from the Adriatic Sea to the Aegean Sea –was observed in the mid-90′ and stimulated intense research. We demonstrate, using an oceanic general circulation model, that the meridional overturning circulation of the Eastern Mediterranean has multiple equilibria states under present-day-like conditions, and that the water exchange between the Aegean and the Adriatic Seas can drastically affect these states. More specifically, we found two stable states and a hysteresis behaviour of deep water formation in the Adriatic Sea when changing the atmospheric (restoring) temperature over the Aegean Sea. In addition, the overturning circulation in both seas exhibits large decadal variability of the deep water formation. The Aegean-Adriatic relationship can be summarized as follows: warm and saline water of the Aegean can either flow in the sub-surface to the Adriatic, switching “on” deep water formation in the Adriatic by increasing its salinity, or the Aegean water can feed the deeper layer of the Ionian and Levantine basins, turning “off” the deep water formation in the Adriatic. The “off” steady state resembles some aspects of the EMT in which the Adriatic source of deep water was weakened when the Aegean source became active. Another noticeable finding of this work is the minor to none dense water outflow from both the Aegean and Adriatic Seas in some of the simulations. When none of the seas produce dense enough water, the Levantine basin deep layers are not ventilated and a sapropel-like period is enabled, as is evident in the Eastern Mediterranean sediments record.

Keywords: Mediterranean Sea, Meridional overturning circulation, Multiple equilibria, Adriatic Sea, Aegean Sea, Eastern Mediterranean Transient

周辺海域の気候変動から孤立した瀬戸内海の30年水温塩分変動について
30-year variation of temperature and salinity in the Seto Inland Sea isolated from the climate change in the surrounding ocean

*磯辺 篤彦[1]
*Atsuhiko Isobe[1]

1. 九州大学応用力学研究所
1. Research Institute for Applied Mechanics, Kyushu University

Using oceanographic data archived in the Marine Information Research Center Ocean Dataset 2005, linear trends of both temperature and salinity from 1963 to 1993 were computed at each grid cell with a horizontal scale of 1/6° over the Seto Inland Sea, Japan. The linear trends were thereafter multiplied by 31 years to compute the increments of temperature and salinity during this period. Over the course of 31 years, summer temperatures decreased significantly both at the sea surface (−1.2 ˚C/31y averaged over the area) and the bottom (−1.7 ˚C/31y), while salinity increased at the sea surface (0.46/31y) and bottom (0.41/31y). In addition, it was found that steric heights computed using temperature and salinity in summer (see Methods) mostly decreases over the Seto Inland Sea during the 31 years (−0.57 mm/y).
It is unlikely that these 31-year trends were caused by surface heat and freshwater fluxes through the sea surface. Of particular interest is the salinity increase, which was revealed in the bottom layer as well as the surface layer. Apparently, this is unlikely to be caused by a secular trend of freshwater flux into the upper layer (precipitation minus evaporation, and/or river runoff). The reasonable explanation is that the dense (cool and saline) Kuroshio intermediate water, uplifted near the coast over the period 1963 through 1993, intruded into the bottom layer of the Seto Inland Sea. The above-mentioned trends were restricted within the Seto Inland Sea. The temperature increment south of Japan was mostly zero during the same period in summer. Moreover, the sea surface height (SSH) within the same area in summer showed an increase of 0.2 (2.0) mm/year during the same period.
In the southwestern Japan Islands, the oceanographic properties of shallow coastal waters exposed to the south are vulnerable to Kuroshio fluctuations that act as outer boundary conditions. The reconstructed SSH data (ReSSH; Hamlington et al., 201, 2112) map averaged over 10 years from 1963 to 1972 suggests that a cold eddy was located off the Kyushu and Shikoku Islands, Japan. However, in the ReSSH map averaged over the period 1984−1993, the cold eddy identified 20 years earlier had mostly disappeared, and it was replaced with a warm eddy. The transition to the warm eddy suggests that the surface speed (hence, volume transport) of the Kuroshio Current south of Japan had increased during the period 1963−1993, because of the recirculating geostrophic flow around the eddy. A geostrophic adjustment associated with the increasing Kuroshio transport results in the thermocline tilting and resultant temperature decreases (salinity increase) close to the Japan Islands. This is consistent with the temperature decrease (salinity increase) in the Seto inland Sea, potentially caused by the subsurface intrusion of the Kuroshio intermediate water. It is however a difficult task to uncover the possible cause(s) of the eddy transition south of Japan; Note that the Kuroshio meander off the Enshu Nada was apparently not a cause, because it is located far east of the Seto Inland Sea. To uncover the cause(s) of the 31-year eddy activity south of Japan, we have to investigate the secular SST/SSH variation, at least, ten times longer than the period in the present study, and it is unfortunately beyond the scope of the conventional physical oceanography.

キーワード：水温塩分30年変動、瀬戸内海
Keywords: 30-year variation of temperature and salinity, Seto Inland Sea

日本海における底層水の形成とその経年変動
Formation of bottom water and its variability in the Sea of Japan

*田中 潔[1]
*Kiyoshi Tanaka[1]

1. 東京大学
1. University of Tokyo

日本海での底層水形成（陸棚水が大陸棚斜面を沈降する過程）について、その力学過程と経年変動を調べた。その結果、以下のことが分かった。冬季のピョートル大帝湾（Peter the Great Bay、以下PGB）では、低温・高塩で高密度の陸棚水が形成されている。このPGB陸棚水は、1980年以前はPGB沖の大陸棚斜面基部（3000 m深）まで時々沈降していた。ところが、1980年代に入ると、それは大陸棚斜面の半分程度（1500 m深）まで沈降することはあったものの、斜面基部（3000 m）まで沈降して底層水を形成することはなかった。しかし、2001年には、顕著に重いPGB陸棚水が作られて、再び大陸棚斜面基部にまで達する沈降が生じた。2001年に底層水形成が復活した理由は、シベリア高気圧の北部とアリューシャン低気圧が強化されて、それらが寒気を北方からPGB周辺に運んだためである。その結果、PGBで強い海面冷却が生じ、日本海での底層水形成に至ったと考えられた。すなわち、日本海底層水の形成は、大気場の経年変動に強く影響を受けている。

キーワード：日本海、底層水形成、経年変動、力学モデル
Keywords: Sea of Japan, Formation of Bottom Water, Interannual variability, Hydrodynamic Modeling