平成 29 年 1 月修士論文要旨

（東京大学大学院　新領域創成科学研究科　海洋技術環境学専攻）

Study on Anthropogenic Carbon Uptake in the Ocean

（海洋中人為起源溶存炭素に関する研究）

学籍番号 47-156653 李　易達

指導教員　河野　健　客員教授

（平成２９年１月 31 日発表予定）

Keywords: 人為起源二酸化炭素，炭素溶存，生物寄与，手法差異

Keywords: Anthropogenic CO_2, Carbon Uptake, Biological Contribution, Methods Comparison

1. Introduction

Climate change is now apparent and it will amplify existing risks and create new risks for natural and human systems [AR5, IPCC] [1]. However, it is very difficult to distinguish the anthropogenic CO_2 emission from total CO_2 in the natural system.

Anthropogenic CO_2 in the ocean interior can be estimated by correcting the measured carbon concentration [Brewer 1978[2], Chen and Millero 1979[3]]. To eliminate the uncertainties due to mixing, Gruber et al. (1996) [4] developed a new technique. Murata et al. (2007) [5] simplified it into dissolved oxygen (DO), and removed the preindustrial preformed data. This method is named as approximation method, in this study.

$$\Delta C_{ant} = {C_{ant}}^{t1} - {C_{ant}}^{t2} \quad (1)$$

$$C_{ant} = \mathrm{C} - \gamma_{C:O} \times AOU \quad (2)$$

where C is the dissolved inorganic carbon (DIC), C_{ant} is the anthropogenic carbon. AOU represents apparent oxygen utilization, which is the difference between saturation oxygen concentration and observed oxygen.

A four-dimensional variation (4D-VAR) system for a quasi-global ocean general circulation model (OGCM) was developed by JAMSTEC and Kyoto University. The scale and the resolution of the model are 75°S-80°N and horizontal 1° × 1°, respectively. Depth from the surface to the bottom, is divided into 46 layers. In this study, I use the 55 years (1957-2011), monthly mean output dataset. Other simulation models under assumptions are developed which are summarized in Table 1. According to the characteristic of these models, carbon is divided into four types which are summarized in Table 2. The different types of carbon which represents different sources, can be calculated as the difference between models. For example, Doi et al. (2015) [5] compared Model 1 and 2 to estimate anthropogenic CO_2 in the ocean. This method is named simulation method, in this study.

Table 1 Models Defined in the ESTOC Model

Models and Datasets	Biogeochemical System	Atmospheric CO_2 Increase
Model 1	○	○
Model 2	○	×
Model 3	×	○
Model 4	×	×

Table 2 Definition of Carbon in the ESTOC data

Contribution Field / Source of Carbon	Ocean Circulation	Biological Process
Anthropogenic	Ca	Ba
Natural Source	Cn	Bn

2. Research Objectives

(1) To discuss the biogeochemical system contribution to the air-sea exchange and indirectly to the carbon uptake, with the ESTOC model, qualitatively by choosing a specific basin.

(2) To calculate the contribution of the biological system to the total carbon, in order to better understand the role of biological cycle in carbon uptake.

(3) To compare the approximation method and simulation method by using the same ESTOC dataset, and discuss the spatial variation of the difference between two methods.

3. Link between Air-sea CO_2 Exchange and the Biological Process in the North Pacific

Average DIC concentration data are all normalized to the average DIC concentration of January, 1991. Differences in DIC concentration between Model 1 and Model 3 (without biological processes) in the Tropical Pacifica (Fig.1) and the South Pacific (not shown) are relatively large, which indicate importance of biological process in the CO_2 uptake to the ocean, while in the North Pacific, the difference is small. To investigate the reason, the horizontal distribution of CO_2 exchanges in Model 1 and 3 were calculated as shown in Fig. 2. In Model 1(Fig. 2 (a)), there is strong east-west contrast in CO_2 gas exchange around 40°N in the North Pacific, and also, the CO_2 exchange is positive in the west and negative in the east. The values of DIC in the west and east have negative correlation (not shown here), so the overall DIC concentration in the North Pacific becomes small. This makes the difference between Model 1 and Model 3 in the North pacific small.

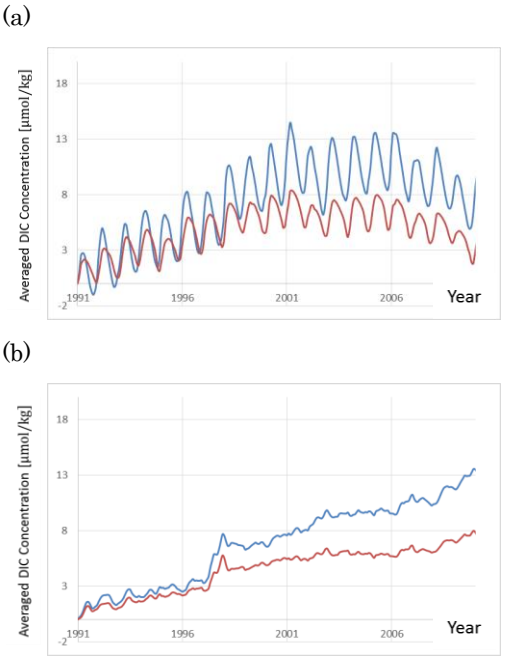

Fig. 1 (a) average DIC concentration in the North Pacific (b) average DIC concentration in the Tropical Pacific; Blue is in Model 1, red is in Model 3. Normalized to January, 1991 [μmol/kg]

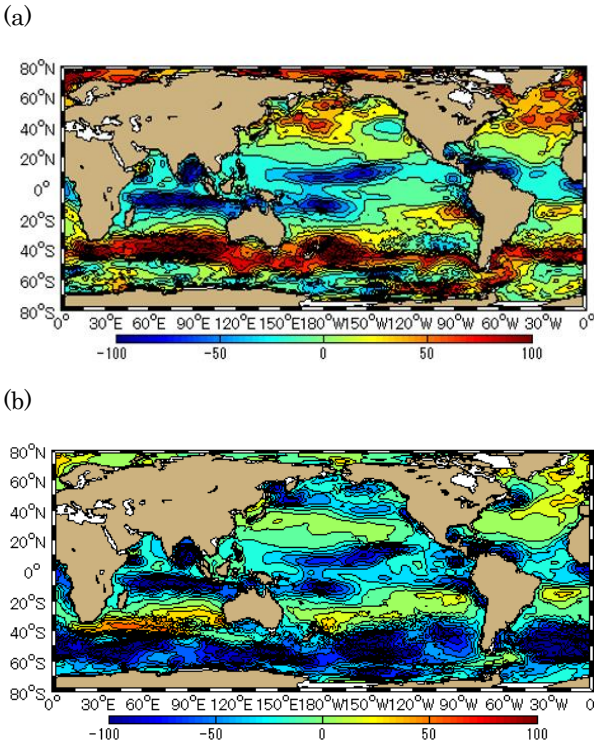

Fig. 2 the Distribution of CO2 Exchange in Air-sea Surface (a) in Model 1 (b) in Model 3. [cm·mol/kg·h]

4. Indication of Biochemical System Contribution to the Carbon Uptake in the ESTOC

The contribution of the biological process to the carbon uptake $(Ba + Bn)$ has not been estimated before. It can be calculated by comparing the models with and without biogeochemical system.

$$Ba + Bn = (Ca + Cn + Ba + Bn) - (Ca + Cn) \quad C_{Bio} = C_{Model\,1} - C_{Model\,3} \tag{3}$$

And the contribution to the anthropogenic carbon uptake (Ba) can be calculated as equation (4).

$$Ba = (Ca + Cn + Ba + Bn) - (Ca + Cn) - \{(Cn + Bn) - Cn\}$$

$$C_{Bio}^{ANT} = C_{Model\,1} - C_{Model\,3} - (C_{Model\,2} - C_{Model\,4}) \tag{4}$$

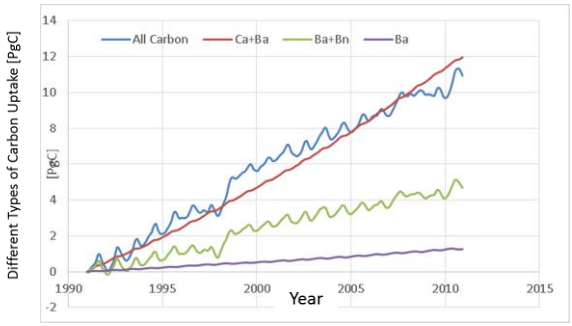

Fig. 3 Biological Contribution, in global-scale between 0-200m, (1991.1-2010.12), normalized to 1991.1 [PgC]

Table 3 Results and Proportions of Biogeochemical system in ESTOC

Carbon Uptake [PgC/yr]		Proportion	
Ba	0.06	$\frac{Ba}{Ba + Ca}$	11.5%
Ba + Bn	0.25	$\frac{Ba + Bn}{All\ Carbon}$	41.5%

The 20 years uptake of $(Ba + Bn)$ and (Ba) were calculated, together with the all carbon uptake $(Ca + Cn + Ba + Bn)$ and total anthropogenic carbon uptake $(Ca + Ba)$, and shown in Fig. 3. And the proportion of the biogeochemical system to all carbon and total anthropogenic carbon uptake is shown in Table 3. The carbon uptake change occurred in 1998 is considered to be an effect of El Niño. The distribution of all carbon and biological contribution in the photic layer (0-200m) was calculated as Fig. 4 and carbon uptake off the South America is very small in El Nino year.

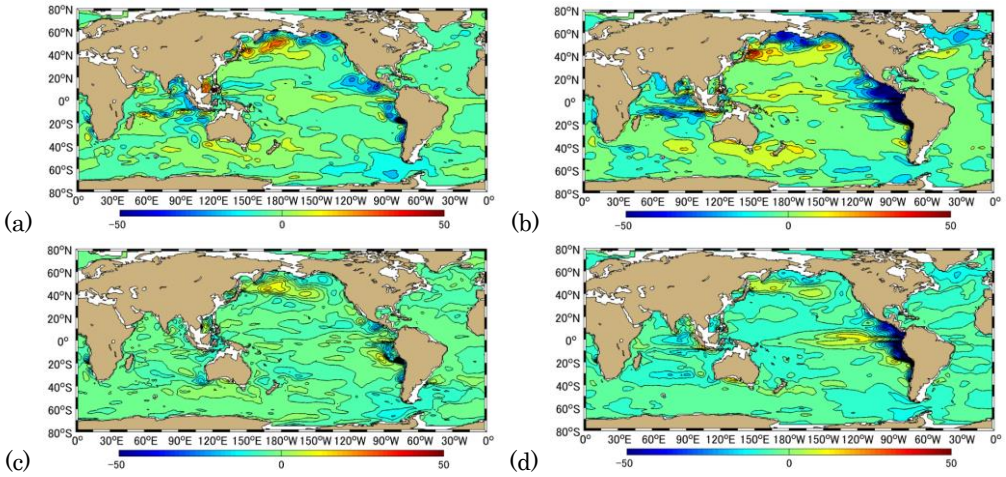

Fig. 4 Carbon Uptake of photic water in the winter (average of Dec. Jan. Feb.), normalized to 1991.1, respectively. (a) all carbon in 1994 (b) all carbon in 1998 (c) biological contribution of 1994 (d) biological contribution of 1998 [PgC]

5. Anthropogenic Carbon Uptake Calculated by Different Methods

In this study, it is assumed that the simulation method reflects the phenomena precisely, therefore, the difference between approximation method and simulation method is considered to be the bias that introduced by the assumption used in approximation method. I calculated the difference between those two methods using the ESTOC data.

$$\text{Difference} = C_{ant}^{Appr.} - nC_{ant}^{Simu.} \quad (5)$$

$$\text{DIfference} = \text{C} - \gamma_{C:O} \times AOU \; - (C_{Model\,1} - C_{Model\,2}) \quad (6)$$

The difference of C_{ant} calculated by the two methods in the global scale is shown in Fig. 5. The anthropogenic carbon uptake calculated by approximation method is 0.74 [PgC/yr], and 0.60 [PgC/yr] by the simulation method. The difference of carbon uptake is 0.14 [PgC/yr], and there is a spatial variation as shown in Fig 6. The largest difference is in the South Pacific and the smallest in the North Pacific. The approximation method underestimates the anthropogenic carbon uptake in the Southern Oceans.

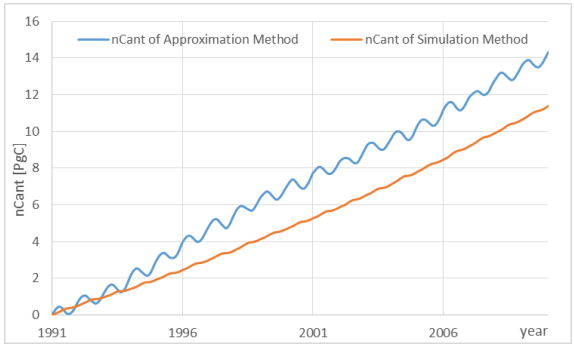

Fig. 5 Anthropogenic Carbon Uptake calculated by the two methods. Blue and red show the approximation and simulation method,

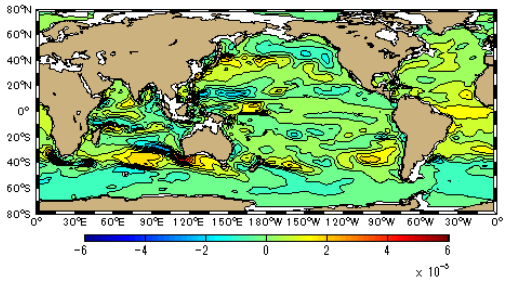

Fig. 6 Distribution of Difference in Equ. (5) [PgC]

6. Conclusion

In this study, the importance of biological process was discussed by using ESTOC model. I found that the biological system is indirectly controlling the CO_2 exchange on air-sea surface through the nitrate distribution (not shown in this abstract) and affect to the horizontal distribution and carbon uptake in the ocean, I also calculated that biological contribution to the carbon uptake to be 41.5% which has never estimated in previous studies. The bias which could be introduced by the assumption when anthropogenic CO2 uptake is calculated from observation results is discussed. I found that the bias is overestimate by 0.14 [PgC/yr], and the spatial variations were discussed in basin scale.

References

[1] Intergovernmental Panel on Climate Change, Fifth Assessment Report

[2] Brewer, P, Direct Observation of oceanic CO_2 increase, *Geophs. Res. Lett., 5(1978)997-1000*

[3] Chen, C and F. J. Mellero, Gradual increase of oceanic CO_2, *Nature, 277(1979)205-206.*

[4] Gruber, N., J. L. Sarmiento, and T. F. Stocker, An improved method for detecting anthropogenic CO_2 in the oceans, *Global Biogeochemical Cycles, 10(1996)809-837.*

[5] Murata, A., Y. Kumamoto, S. Watanabe, Decadal increases of anthropogenic CO_2 in the South Pacific subtropical ocean and 32°S, *Geophs. Res. Lett. , 42(2007)4903-4911.*

[6] Doi, T, S. Osafune, N. Sugiura, Multi-decadal change in the dissolved inorganic carbon in a long-term ocean state estimation, *J. Adv. Model Earth SY. 7(2015)1885-1900.*