# Data Synthesis for Biogeochemical Variables by Using a 4 Dimensional Variational Approach

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A 4-dimensional variational data assimilation system has been used to better define the 50-year state estimation of the global ocean. The synthesis of available observations and a pelagic ecosystem model based on nitrogen cycle produces a dynamically self-consistent dataset. In our 4D-VAR approach, optimized 4-dimensional datasets are sought by minimizing a cost function on the basis of Green's function approach. The assimilated elements are the climatological monthly mean nitrate from WOA05, monthly mean ocean color data from SeaWiFS, and annual mean chlorophyll-a from WOA98 as detritus. Tentative analyses imply that the obtained ocean state estimation possibly has greater information than do models or data alone.

**Keywords**: Ocean, Data assimilation, biogeochemistry

## 1. Introduction

The ocean acts as a major sink for anthropogenic $CO_2$ (*e.g., Solomon et al., 2007*)[1]. To describe the dynamic state of $CO_2$ in the ocean is a major concern for researchers of global change. *Rienecker et al.* (*2010*)[2] mentioned an advantage of "Integrated Earth System Analyses" at OceanObs'09. A physical-biogeochemical ocean model, coupling with the atmosphere, sea-ice, and also with the land surface is a promising in climate research in the future.

In this study, we have conducted a global ocean synthesis on the basis of in situ bio-geochemical observations, satellite images and a global lower-trophic ecosystem model through a 4D-VAR data assimilation to obtain a comprehensive 4-dimensional integrated dataset. The dataset include an estimate of the global biogeochemical variables toward an Integrated Earth System Analyses.

## 2. Model

The background dynamical ocean state is derived from ocean data assimilation system, based on ocean general circulation model (OGCM); version 3 of the GFDL Modular Ocean Model (MOM) (*Pacanowski and Griffies, 1999*)[3] with major physical

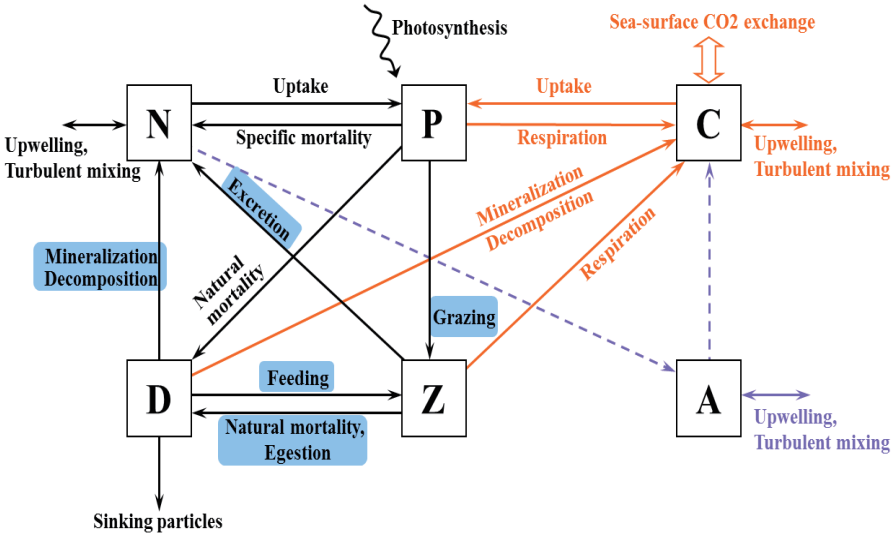


Fig. 1 Schematic view of NPDZC-model [see the text for details].

parameter values determined through a variational optimization procedure (*Menemenlis et al., 2005*)[4]. The horizontal resolution is 1° in both latitude and longitude, and there are 46 vertical levels for the global ocean basin. The ocean data assimilation system is on the basis of 4-dimensional variational technique to obtain a comprehensive 4-dimensional dynamical ocean state from 1957 to 2006 (*e.g., Masuda et al., 2010*)[5].

We introduce a new bio-geochemical model NPDZC-model by using the obtained dynamical ocean state. It consists of 6 state variables representing the biomass of phytoplankton (P), zooplankton (Z), nitrogen (N), carbon (C), and detritus (D). This model is the pelagic ecosystem model based on nitrogen cycle and is optimized for the Earth Simulator. A NPDZC-model added function for the carbon cycle to the original NPDZ-model (Fig. 1).

## 3. Optimization

We carried out a data synthesis scheme by which available information from observations is integrated to obtain a set of optimized model parameters. This scheme is a kind of 4-dimensional variational method through Green's function approach. *Menemenlis et al.* (*2005*)[4] successfully apply this approach to OGCM. We search an optimal set of major model parameters for NPDZC-model by using WOA05 monthly mean nitrate, pseudo detritus values converted from WOA98 annual mean chlorophyll-a, and SeaWiFS monthly mean value (Sep. 1998 ~ Aug. 2008) as the observation of phytoplankton.

## 4. Results

The obtained synthesis results were compared with observed data in WHP (WOCE Hydrographic Program) revisit survey. P14 line near 179E was adopted in comparison. (The revisit cruise on P14 was carried out in 2007 by JAMSTEC R/V MIRAI.) Figures 2 and 3 show the distribution of total carbon and alkalinity, respectively. These panels illustrate the synoptic patterns are by and large consistent with observations.

## 5. Concluding Remarks

Advanced ocean data assimilation techniques have led to better understanding of ocean climate change and will possibly

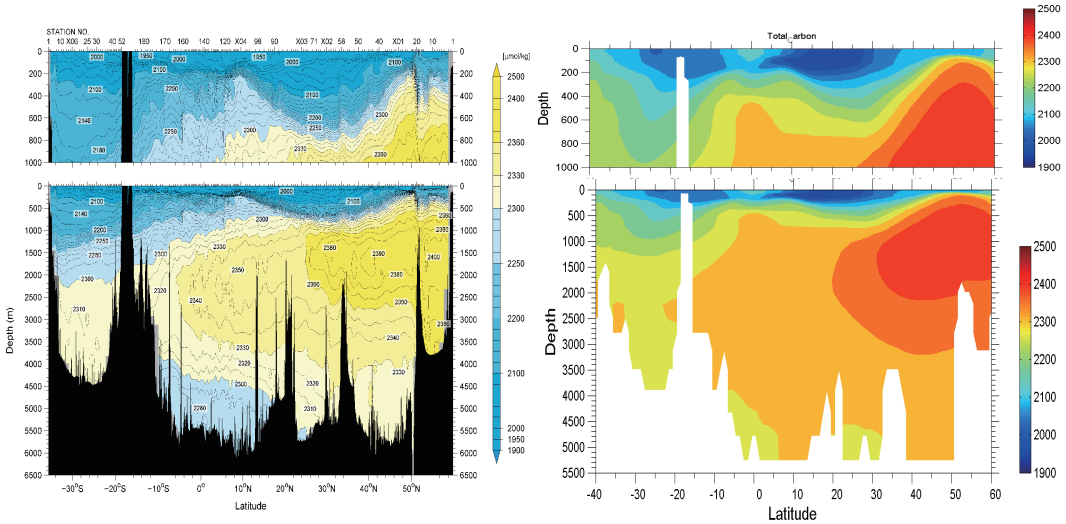


Fig. 2 Distribution of DIC in a vertical cross section along P 14 line; observation (left) and estimation (right)

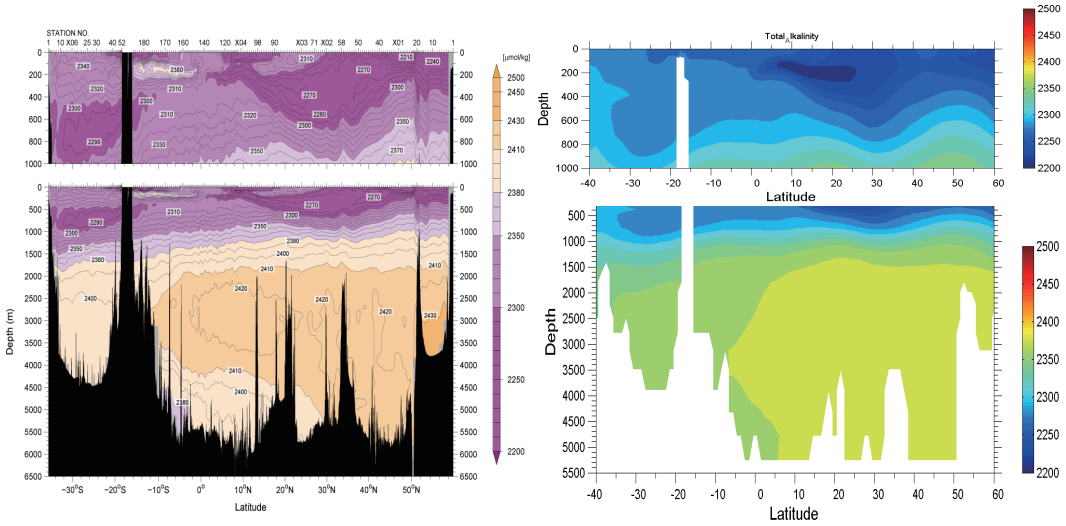


Fig. 3 Same as Fig. 2 but for Alkalinity.

contribute to the resolution of scientific issues on global warming. This report implies that our synthesis scheme for sparse observations including bio-geochemical parameters is possibly promising and useful for “Integrated Earth System Analyses”.

## Acknowledgement

We thank Dr. A. Murata, Dr. S. Kouketsu for helpful discussion.

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# 四次元変分法を用いた生物化学変量観測データの統合

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海洋は人為起源二酸化炭素の主たる吸収源の一つであることが知られている。全球海盆での溶存無機炭素の動態を把握することは地球温暖化をはじめとする気候変動現象を解明する上で重要な課題である。本研究では四次元変分法海洋データ同化システムを用いて 50 年間にわたる全球海洋の環境再現実験を実施した。四次元変分法手法のうち Green's 関数法を応用し最適なモデルパラメータを求めることで、入手可能な海洋観測データと窒素循環をベースとした海洋生態系モデルの統合を図り、力学的整合性のとれた統合データセットを作成する。用いた観測データは WOA05 の気候学的月平均硝酸塩データ、SeaWiFS の海色データ、および WOA98 の気候学的年平均 chlorophyll-a データをデトリタスに換算したものである。得られた結果は統合データセットが観測情報を反映しつつ四次元に均一な品質を持つデータとして解析研究に応用でき得ることを示唆している。

キーワード:海洋, データ同化, 炭素循環