A Long-term Ocean State Estimation by using a 4D-VAR Data Assimilation Approach

Project Representative

Shuhei Masuda Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology

Authors

Shuhei Masuda*1, Nozomi Sugiura*1, Toshimasa Doi*1, Yoshihisa Hiyoshi*2, Yuji Sasaki*2 and Toshiyuki Awaji*2

*1 Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology

*2 Data Research Center for Marine-Earth Sciences, Japan Agency for Marine-Earth Science and Technology

We have conducted a global ocean synthesis on the basis of in-situ temperature and salinity observations, satellite altimetry and a global ocean general circulation model through a 4D-VAR data assimilation to obtain a comprehensive 4-dimensional integrated dataset from the sea surface to the ocean bottom for all the major ocean basins for the period of 1967-2009. The assimilated elements are historical hydrographic data of temperature and salinity from the ENSEMBLES (EN3) data set, NOAA Optimum Interpolation SST values and sea level anomaly data derived from the high-precision multi-satellite altimetry products were distributed by Aviso. The obtained dynamically self-consistent 4-dimensional dataset can offer greater information content on ocean climate changes than can be derived from models or data alone.

Keywords: Ocean, Data assimilation, Climate change, 4D-VAR

1. Introduction

The spatio-temporal coverage of hydrographic data is still sparse. Data assimilation approaches have recently focused on the derivation of an optimal synthesis of observational data and model results for better descriptions of the ocean state (*e.g., Stammer et al., 2002*)[1].

Within this backgrounds, (*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 temperature and salinity observations, satellite altimetry and a global ocean general circulation 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 with a new lower-trophic ecosystem model toward an Integrated Earth System Analyses.

2. Model

The used OGCM is based on version 3 of the GFDL Modular Ocean Model (MOM) (*Pacanowski and Griffies, 1999*)[3] with major physical 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 adjoint code of the OGCM was obtained using the Transformation of Algorithms in Fortran (TAF).

Our ocean data assimilation system has been executed on the Earth Simulator 2 to obtain a comprehensive 4-dimensional dataset (*e.g., Masuda et al., 2010*)[5]. The assimilated elements are historical hydrographic data of temperature and salinity from the ENSEMBLES (EN3) dataset which was quality-controlled using a comprehensive set of objective checks developed at the Hadley Centre of the UK Meteorological Office (*Ingleby and Huddleston, 2007*)[6]. In addition of EN3 dataset, recent data obtained/compiled in JAMSTEC (independent MIRAI RV profiles) are simultaneously incorporated. NOAA Optimum Interpolation SST (NOAA_OI_SST_V2) values, and sea-surface dynamic-height anomaly data derived from the high-precision multi-satellite altimetry products produced by Ssalto/Duacs are also assimilated.

A new bio-geochemical model NPDZC-model was introduced based on 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).

3. Ocean State Estimate

The assimilation is based on a 4D-VAR adjoint approach which can precisely determine the time-trajectory of the ocean states, and thus can provide analysis fields in superb quality through 4-dimensional dynamical interpolation of in-situ observations for water temperature, salinity and sea surface height anomaly, as obtained from various instrumental sources. Figure 1 shows estimated sea surface and deep water temperature distributions in December 1980, 2005, and 2008. Gradual warming trend at each depth is apparently visible (*e.g., Fukasawa et al., 2004*)[7]. The analysis fields successfully capture the realistic time trajectory of ocean properties from 1957 to 2009.

4. Applications to Bio-geochemical Model

We estimated the global biogeochemical variables with a new lower-trophic ecosystem model (Fig. 2). The 53-year synthesized ocean dataset provides a dynamically self-consistent

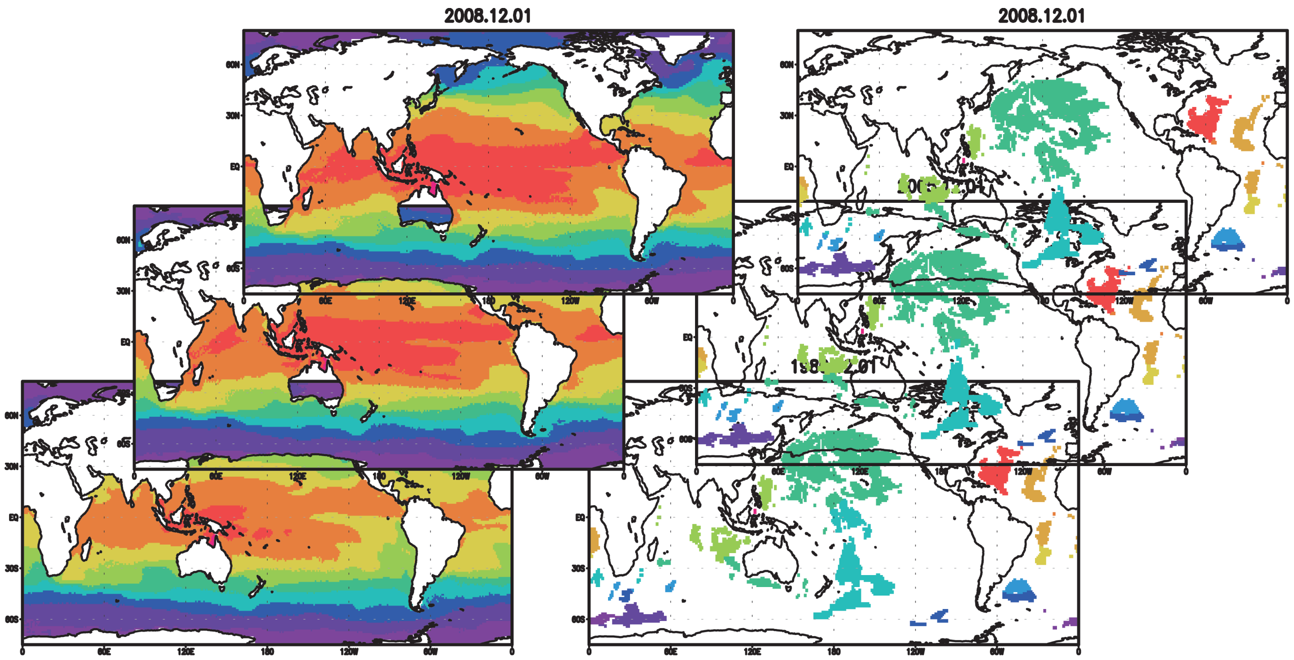

Fig. 1 Sea Surface Temperature and 5000-m depth water temperature estimated form 4D synthesis dataset.

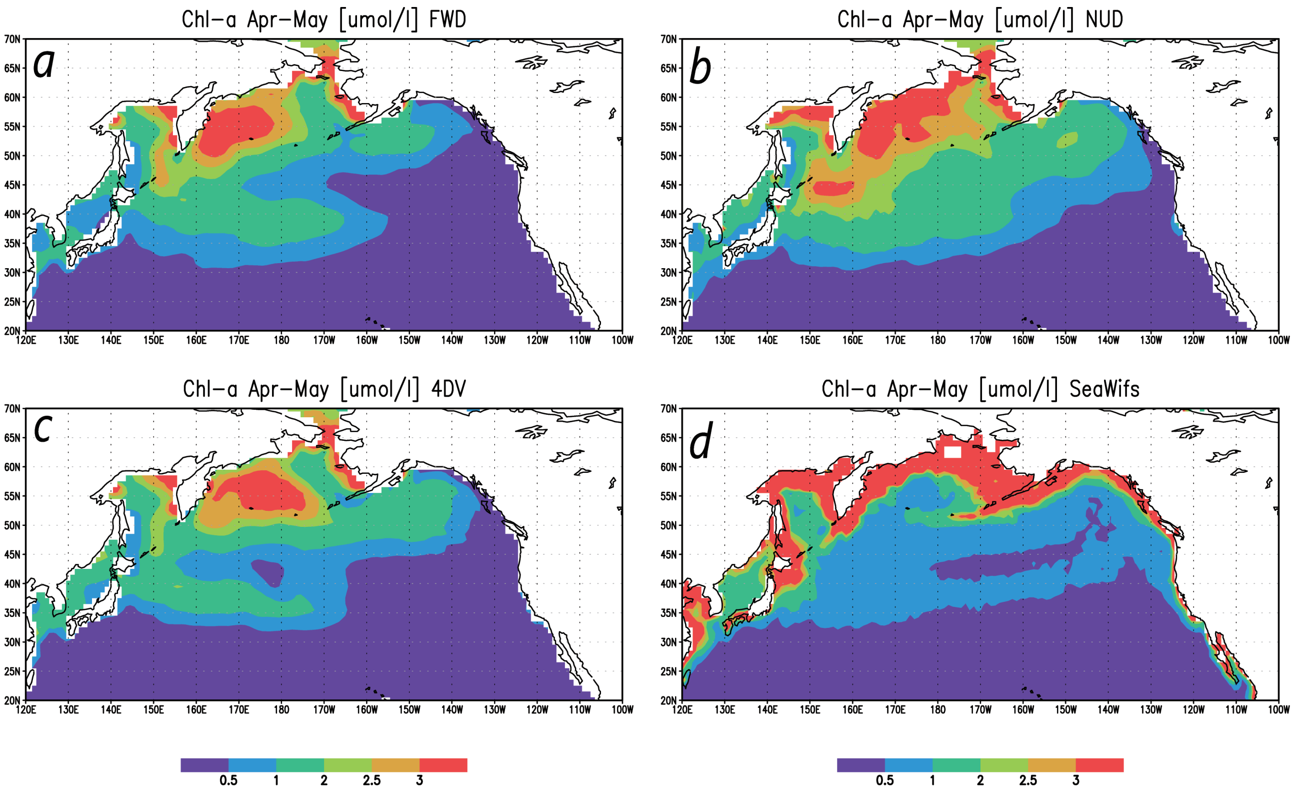

Fig. 2 Distribution of estimated Chlorophyll-a; (a) simulation, (b) simulation with ocean property nudging, (c) 4D-VAR procuct, and (d) SeaWifs satellite product.

ocean current field for the ecosystem model. Bio-geochemical model parameter values will be optimized in the global ocean through the Green's function approach. The optimized parameter set enables us to estimate a realistic time-varying bio-geochemical fields consistent with observations, which should offers a better description of oceanic material transport inclusive of carbon.

5. Concluding Remarks

Advanced ocean data assimilation techniques have led to better understanding of ocean climate change and will possibly contribute to the construction of an optimal ocean observing system (*e.g., Oke et al, 2009*)[8]. Our data assimilation system can provide a model sensitivity, which facilitates the identification of the mechanism, origins and pathways of specific climate changes, thus would lead to an effective strategic planning for the spatial and temporal deployment of measurement instruments and hydrographic surveys. It is a promising perspective of our research.

Acknowledgement

We thanks J. P. Matthews, Y. Ishikawa, and M. Kamachi for helpful discussion.

References

[1] Stammer, D., C. Wunsch, I. Fukumori, and J. Marshall, "State Estimation in Modern Oceanographic Research", *EOS, Transactions*, American Geophysical Union, Volume 83, Nr. 27, p. 289, 294-295, 2002.

[2] Rienecker, M., T. Awaji, M. Balmaseda, B. Barnier, D. Behringer; M. Bell, M. Bourassa, P. Brasseur; L.-A. Brevik, and J. Carton, "Synthesis and Assimilation Systems - Essential Adjuncts to the Global Ocean Observing System" *in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 1)*, Venice, Italy, 21-25, 2010.

[3] Pacanowski, R. C., and S. M. Griffies, *The MOM 3 manual*, report, 680 pp., Geophys. Fluid Dyn. Lab., Princeton, N. J, 1999.

[4] Menemenlis, D., I. Fukumori, and T. Lee, Using Green's functions to calibrate an ocean general circulation model, *Mon. Wea. Rev.*, 133, 1224-1240, 2005.

[5] Masuda, S., T. Awaji, N. Sugiura, J. P.Matthews, T. Toyoda, Y. Kawai, T. Doi, S. Kouketsu, H. Igarashi, K. Katsumata, H. Uchida, T. Kawano, and M. Fukasawa, Simulated Rapid Warming of Abyssal North Pacific Waters, *Science*, 329, 319-322, DOI: 10.1126/science.1188703, 2010.

[6] Ingleby, B. and M. Huddleston, Quality control of ocean temperature and salinity profiles - historical and real-time data, *Journal of Marine Systems*, 65, 158-175, DOI: 10.1016/j.jmarsys.2005.11.019, 2007.

[7] Fukasawa, M., H. Freeland, R. Perkin, T. Watanabe, H. Uchida, and A. Nishina, Bottom water warming in the North Pacific Ocean, *Nature*, 427, 825-827, 2004.

[8] Oke, P. R., M. A. Balmaseda, M. Benkiran, J. A. Cummings, E. Dombrowsky, Y. Fujii, S. Guinehut, G. Larnicol, P.-Y. Le Traon, and M. J. Martin, Observing system evaluations using GODAE systems. *Oceanogr.*, 22, 144-153, 2009.

四次元変分法海洋データ同化システムを用いた全球海洋環境の再現

プロジェクト責任者
増田　周平　　海洋研究開発機構　地球環境変動領域
著者
増田　周平 *1，杉浦　望実 *1，土居　知将 *1，日吉　善久 *2，佐々木祐二 *2，淡路　敏之 *2
*1　海洋研究開発機構　地球環境変動領域
*2　海洋研究開発機構　地球情報研究センター

船舶、衛星観測などから得られる海洋観測データの時空間な分布密度は比較的観測の多い水温データでも地球規模の気候変動研究を進めるうえで十分に密であるとは言えない。気候変動現象をより精緻に解析するためにはデータ同化技術を用いた力学補完が有効である。本研究では四次元変分法海洋同化システムを用いて、高精度な海洋環境再現データを作成した。また、このデータセットを用い、生物化学変量の推定も行った。

キーワード: 海洋, データ同化, 気候変動, 4D-VAR