Improved Estimates of the Dynamical Ocean State by using a 4D-VAR Adjoint Method

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The spatio-temporal coverage of hydrographic data is still sparse. To obtain a 4-dimensionally continuous state estimation of the global ocean, 4-dimensional variational (4D-VAR) data assimilation system has been developed. This system is capable of providing an optimal synthesis of the observational data and a climate model by solving a nonlinear least square problem. 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

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 [1]. The synthesis efforts so far have mainly directed the attention to the upper ocean since observations of changes in the properties of ocean waters have been restricted to surface or intermediate-depth waters.

Based on high quality observational survey, recent studies have found the sobering fact that the deepest waters of the major ocean have warmed significantly during the recent decades [2]. This bottom-water warming is of particular interest as they can constrain estimates of the variability of abyssal circulation. The latter have implications for large-scale thermohaline transport and thus for the global 3-dimensional heat budget that is presently of vital concern in conjunction with climate warming.

In this study, we will take the deepest waters into consideration through data assimilation procedure in order to more precisely assess various climate variabilities.

2. Model

The used OGCM is based on version 3 of the GFDL Modular Ocean Model (MOM) [3] with major physical parameter values determined through a variational optimization procedure [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 system has been executed on the Earth Simulator 2 to obtain a comprehensive 4-dimensional dataset [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 [6]. In addition of EN3 dataset, recent data obtained/compiled in JAMSTEC (independent MIRAI RV profiles and a climatology of subsurface 2-dimensional velocity estimated from Argo floats [7]) 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.

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. The analysis fields successfully capture the realistic time trajectory of ocean properties and observed patterns of ocean circulation and surface air-sea heat fluxes. For example, Fig. 1 shows estimated steric height distribution in an El Niño year. Significant sea level rises appear in the eastern equatorial Pacific and central Indian Ocean in conjunction with interannual changes in oceanic heat storage. Recent-day sea level change is of considerable interest because of its potential impact on human populations living.

4. Applications to Climate Research

By using this ocean state estimation, the bottom-water warming is assessed. The bottom water warming in the North Pacific is successfully reproduced in our reanalysis field (Fig. 2), which can lead to better understanding of the warming trend of the global ocean. Detailed analysis on the basis of model formalism uncovered a new finding that temporal change in the horizontal advection mainly causes variations of the local time change, implying that the changes in the abyssal circulation constrain the bottom-water warming [5].

5. Concluding Remarks

By using a 4-dimensional variational adjoint method, we have obtained an oceanic reanalysis dataset for 1957-2006. The reconstructed field, which has dynamical consistency, reflects most of the familiar gross features of past studies. Hence, our product is useful for understanding long-term oceanic variabilities. The dynamical analysis on the bottom-water warming led to new findings of its mechanism. Our variational data assimilation approaches, in turn, can possibly help construct an optimal observing system.

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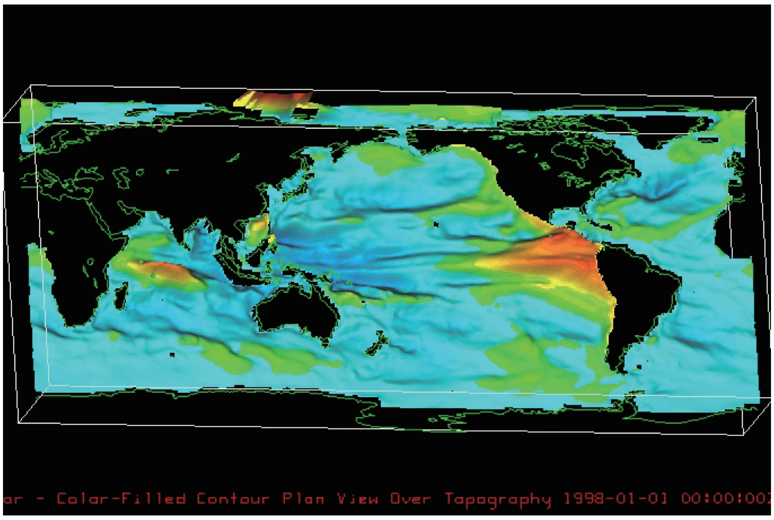

Fig. 1 Distribution of steric sea level change for Jan 1998 (El Niño year) estimated from 4-dimensional synthesis dataset.

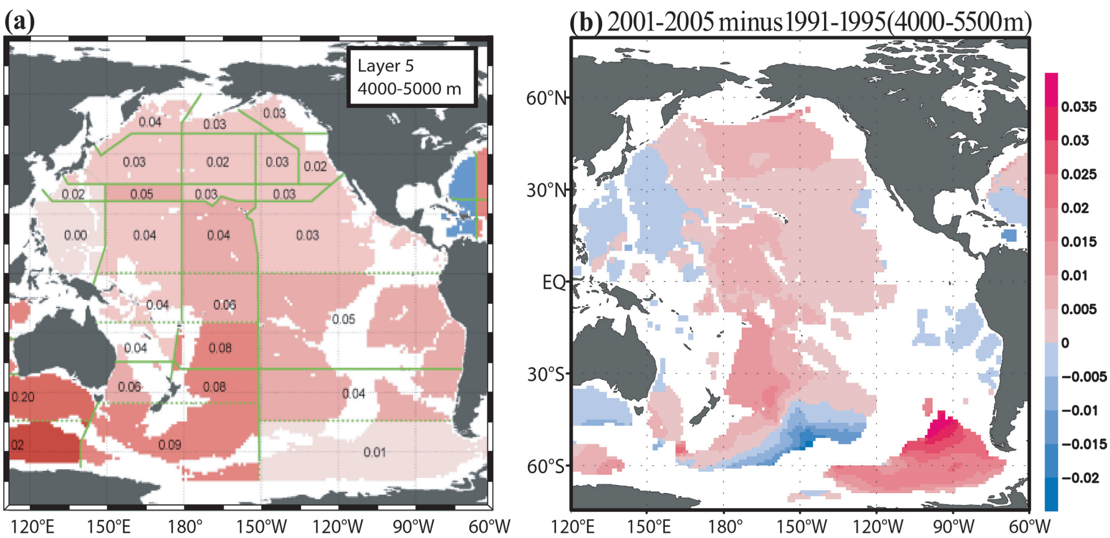

Fig. 2 Bottom water warming in the Pacific Ocean below 4000m-depth; (a) observed heat content trend and (b) estimated temperature trend.

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四次元変分法海洋データ同化システムを用いた海洋環境再現実験

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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的な分布密度は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用である。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。このデータセットを用い、深層昇温現象など地球規模での海洋環境変動の力学解明に取り組み、そのメカニズムの一端を明らかにした。

キーワード: 海洋, データ同化, 気候変動, 4D-VAR