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Japan Agency for Marine –Earth Science and Technology

Heat content increase detected broadly in the deep ocean ~ Highly accurate observations and the state-of-the-art assimilation technique reveal recent changes in deep ocean~

Overview

Researchers from the Institute of Research Institute for Global Change (RIGC) at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) calculated basin-scale and global ocean decadal heat content (HC) change rates from WOCE*1 surveys (in the 1990s) to the revisits (in the 2000s)*2 for waters below 3000 m, and estimated the global heat content change in the deep ocean. Uncertainties associated with the estimation were also evaluated, using a data assimilation system*3 for the ocean circulation. The heat content increase in the deep ocean was 8-20% of that in the surface layers obtained in previous studies.

This study also showed large uncertainties for the estimates, which suggested that more intensive observations and long-term monitoring of the deep ocean are imperative to estimate the changes precisely.

Background

Ocean heat content changes are one of the major factors in the heat budget of the Earth, and sometime affect our living temperature, as the total capacity of heat in the ocean is much larger than that in the air. Therefore, to monitor heat content changes in the deep ocean is considered to be important to understand the long-term climate variability. Although the careful analyses in previous studies detected significant temperature differences near the ocean bottom, the HC changes in the global deep ocean has not been well described.

Methods

Researchers calculated basin-scale and global ocean decadal heat content changes from the highest accurate hydrographic observations, which have been carried out by JAMSTEC and other institutes in the world under international projects. They evaluated the uncertainty in the estimation of heat content changes in the deep ocean by using ocean reanalysis product developed from a global data assimilation system that can optimally synthesize observations and model results.

Results

Heat content increases were broadly detected in the deep ocean. The increases were largest around Antarctica, and seem to be distributed to the western South Atlantic and reached the North Pacific through the western South Pacific (Fig. 1). The sum of these heat content changes in the deep

ocean was $8*10^{20}$ J / yr, and 8-20% of those in the upper layer, which were estimated in previous studies. Furthermore, the increase was large in comparison with other components in the earth's heat budget (Table 1). The confidence interval (99%) for this estimation was 4-10 J / yr.
Assuming the warming of 0.02 degree /yr after the 1980s was the average value for the whole air column, which was detected in observations in the troposphere, the heat content changes of the air were estimated to be about $1 * 10^{20}$ J / yr. Thus, the heat content changes ($4\text{-}10 * 10^{20}$J / yr) estimated for the deep ocean are not negligible to understand the heat budget.

Future perspectives
As heat content changes in the deep ocean are considered to be related to relatively abrupt large-scale climate changes, which sometimes appeared in the paleoclimate records. Monitoring changes in the deep ocean can be also important to know the recent climate change. As the temperature changes in the deep ocean were extremely small, it is important to obtain periodic and highly accurate observations using research vessels, as seen in this study. Researchers plan to conduct such observations continuously in the future in waters that have large deep-water temperature fluctuations (e.g., in the Indian and the Southern Oceans).
Given the large bias in the heat budget estimation on the earth (Table 1), a more extensive observation network and development of the comprehensive observation techniques (e.g., satellite observation of radiation escaping to space, and long-term monitoring ocean and air temperatures) are necessary to improve the estimation. For better estimates of ocean heat content change, which is one of the major factors in the Earth's heat budget, researchers are developing a new drifting float (Argo float) for the deep ocean, and continuously developing simulation models and reanalysis methods.

***1. WOCE (World Ocean Circulation Experiment)**
From 1990 to 1998, as part of the World Climate Research Program (WCRP), the World Ocean Circulation Experiment (WOCE) was implemented to collect the data necessary to develop numerical models that are capable of describing the present state of the ocean and predict its evolution. In this experiment, standard methods for data processing, synthesis, and publishing were established.

***2. Revisits of WOCE**
The Climate Variability and Predictability Project (CLIVAR) enhances WOCE research results by updating the knowledge on the amount of ocean heat and freshwater transport obtained from WOCE, monitoring and studying ocean changes on decadal or shorter time scales, and providing data to evaluate climate system models. Under this project, the revisit observations were carried out. In 2007, the Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP)*4 was established by groups of researchers, who conducted ship-based observations with support from the UNESCO IOC (Intergovernmental Oceanographic Commission) Executive Council session in June 2010. The Japan Agency for Marine-Earth Science and Technology and the Meteorological Agency participated in GO-SHIP from Japan.

***3. Data assimilation system**
Oceanic data assimilation is a process that incorporates (assimilates) observational data into a numerical model (e.g. OGCM) using an optimization

procedure, to minimize model errors and enhance the representation of the ocean state. In other words, data assimilation dynamically interpolates spatially and temporally sporadic in-situ observations using OGCM. In this study, a 4D-VAR Ocean Data Assimilation System developed by Kyoto University and JAMSTEC was used.

***4. Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP)** is an international initiative to collect high-quality measurements of oceanographic parameters in the global ocean, including deep waters (more than 2000 meters) that account for 40 % of the total volume of the ocean. In Japan, Japan Meteorological Agency and JAMSTEC lead this international observation program.

Appendix

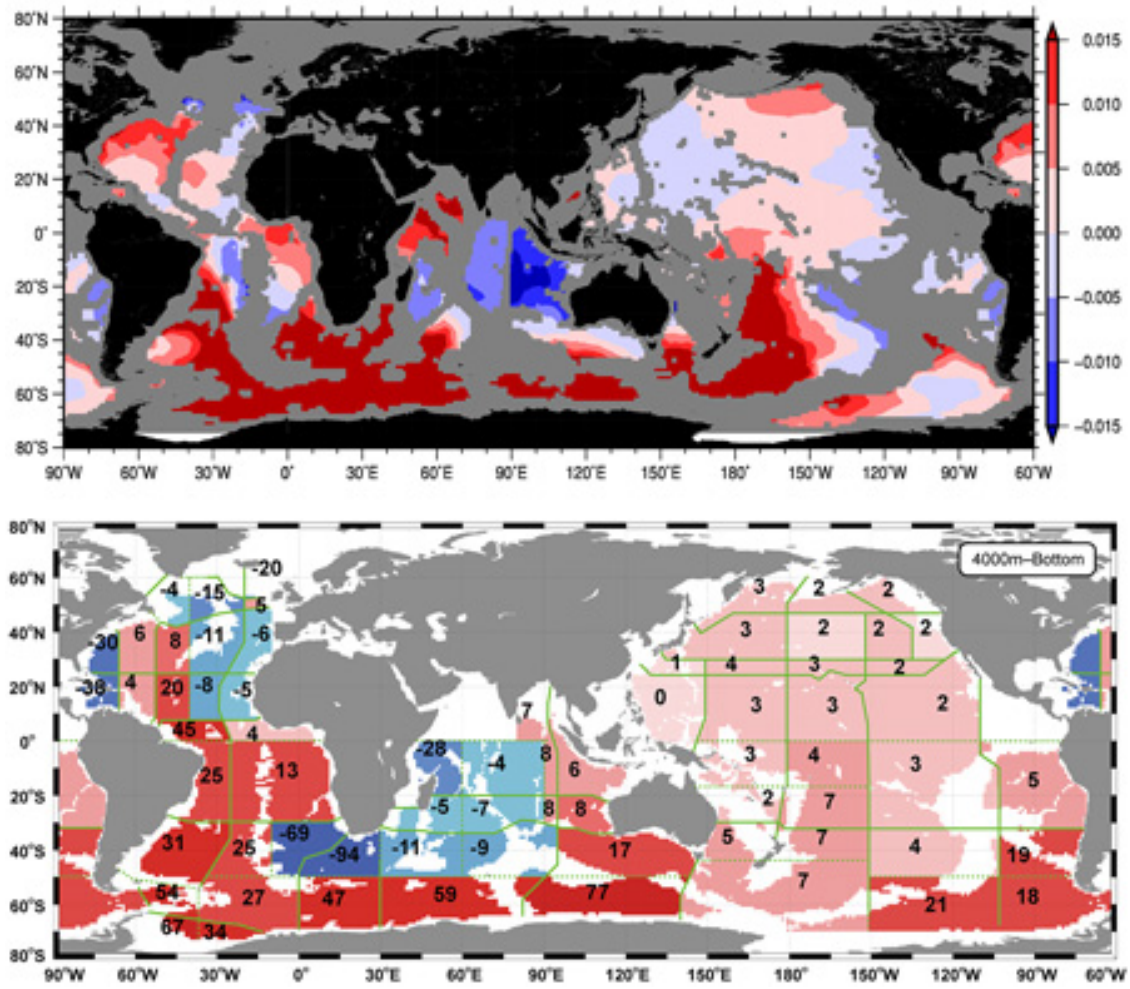

Figure 1. Box-mean temperature increase from WOCE to the revisits in the deep ocean estimated from the reanalysis data (upper) and real observations (lower).

Heat content and radiation changes for the earth in previous studies				Result in this study
Net radiation	Upper ocean	Ice melting	Sun activity	Deep ocean (3000m-bottom)

changes from human influences	(0-900m)		changes	
145?	20-95	2-3	16	4-10

Table 1. Recent heat budget of the earth (*10^{20} / yr) from 2003-2009, which is adopted from Trenberth ,2009, except for the deep ocean.

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