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Japan Agency for Marine-Earth Science and Technology

Data Assimilation System Reveals Decadal Link between North Pacific Warming and Ocean Climate Change in Antarctica

Overview

Shuhei Masuda and his colleagues from the Research Institute for Global Change, and the Data Research Center for Marine-Earth Sciences, of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) reported simulation results showing that bottom water warming in the North Pacific is led by the increase in the surface air-sea heat flux (a decrease in heat transfer from the ocean to the atmosphere) off the Adelie Coast of Antarctica, and this link is established over only 4 decades, much shorter than that required by the conventional mechanism which relies on water mass movement in the deep ocean (800 to 1000 years). The findings were obtained through computer simulations by using a four-dimensional variational (4D-VAR) data assimilation system for global ocean basin (*1) developed under JAMSTEC-Kyoto-University collaborative program. They revealed how the oceanic heat content in the deep ocean changes, offering significant implications for climate change prediction and the reduction in its uncertainties.

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Title : Simulated rapid warming of abyssal North Pacific waters
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Background

High-quality hydrographic surveys conducted in 1985 and 1999 along 47°N in the North Pacific have revealed that the deepest waters have warmed by about 0.005°C during this period (Fig. 1). A similar warming in the deep ocean has been reported in the Atlantic and Indian oceans since the turn of this century. The specific heat of water is about 1,000 times that of the air. Even a small change in water temperature alters global heat balance and possibly affects climate variabilities in the world. The bottom-water warming therefore is attracting the attention of the world’s scientists as a key factor for better understanding global change. The ocean is changing at a variety of spatial and temporal scale. Compiling sparse observations might not lead to any pioneering scientific work. In particular, the difficulty to obtain accurate profiles in the deep ocean prevents the researchers from revealing the causes of the bottom-water warming and its relationship with climate change. To compensate this, numerical model simulations are used, but they can only offer some conceptual implications.

Summary of methods

To determine the mechanism responsible for the observed bottom-water warming in the North Pacific, Masuda and his team performed an adjoint sensitivity analysis (*2) using a four-dimensional variational (4D-VAR) data assimilation system on the “Earth Simulator” supercomputer. The system was then applied to a global ocean synthesis on the basis of in situ observational data and an ocean general circulation model (OGCM) for the global basin. Taking advantage of the obtained ocean synthesized dataset (*3), the team examined the detailed mechanism and the origin of the bottom-water warming

Results and discussions

The team performed an adjoint sensitivity analysis designed to define the mechanism causing the bottom-water warming at a depth of 5,200 meters at 47°N, 170 °E in the abyssal North Pacific, tracing back the abyssal water temperature anomaly backward in time. The results show that the warming signal travels southward in the Pacific Ocean floor in reverse chronological order and eventually reaches to the subsurface region off the Adelie Coast over a 40-year period (Fig.2). In addition, the ocean synthesized dataset, provided forward in time, reveals that the bottom-water warming is attributed to a reduction in the cold water formation around Antarctica. A thinning of abyssal layers caused by the reduction in a Southern Ocean source region leads to changes in the pressure force locally and weakening the deep water current through an action of internal oceanic waves. Bottom-water warming could then be achieved by a change in the heat budget in the deep ocean at the relatively short time scale in contrast to the estimates from observed carbon isotope ratios (800 to 1,000 years).
The discovery here of an invasive and rapid teleconnection between polar surface air-sea heat flux change and distant bottom-water warming has innovative implications in the future study of global climate change.

Future perspective

The ocean is vast and diverse. It is difficult to understand the ocean state correctly and predict its future conditions accurately by merely accumulating in-situ observations. The use of the advanced 4D-VAR data assimilation system on the Earth Simulator has overcome this difficulty by providing an ocean synthesized dataset that is capable of representing the physical ocean state for the 20th century.

The results here provide clues for better understanding the detailed mechanism for the temporal change in the ocean heat content, and highlight that the data assimilation system could be one of the vital tools for ocean climate researches.

Climate change research, which focus on the phenomena on a centennial timescale, has paid little attention to changes in the deep ocean heat content. The computer simulations in this study revealed a rapid teleconnection between changes in the surface air-sea heat flux off the Adélie Coast of

Antarctica and the bottom-water warming in the North Pacific, highlighting the importance of deep water profiles in the climate research on such a time scale. Furthermore, given the important role of deep waters in global ocean nutrient supply, continuous monitoring of global ocean basins and the development of assimilation techniques should be indispensable for the comprehensive understanding of the global mass transport and heat distribution, integrated management of ocean resources toward for a sustainable society, and the reliable prediction for the ocean environmental changes. Assuming a leading role in the international framework for the promotion of accurate oceanographic measurements, JAMSTEC is working to develop a cutting-edge data assimilation system that can represent the ocean states not only with physical variables (e.g., water temperature or salinity), but also with biogeochemical compositions.

On the other hand, the results imply the actual occurrence of the significant change in surface air-sea heat flux around Antarctica in the past time, which underlines the urgency of a long-term prediction collaborated with the global climate change research activities and monitoring efforts. JAMSTEC plans to conduct an observation expedition onboard the Oceanographic Research Vessel Mirai off the Adelie Coast in 2012. A new observatory buoy durable in the Antarctic region is also being developed.

***1. 4D-VAR ocean 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. The 4D-VAR Ocean Data Assimilation System used in this study synthesizes the hydrographic data available for all vertical levels (from the sea surface to the bottom) and the simulated results from OGCM through a variational optimization procedure, allowing for the reliable temporal representation of three dimensional ocean state (thereby, four dimensional representation). It is unique in terms of its capability of assimilating global ocean profiles for all vertical levels and hence has been of major interest to many scientists.

***2. Adjoint Sensitivity analysis**

A kind of numerical inverse analysis that gives the temporal rate of change of a physical variable in a fixed time and space when model variables (e.g., water temperature, velocity, or surface air-sea fluxes) are arbitrarily changed. This is equivalent to specifying the "sensitivity" of a variable to small perturbations in the parameters governing the oceanic state. The 4D-VAR data assimilation system used here allows for tracing the causes of anomalies (climate fluctuations) backward in time, adhering to the physical procedure of the numerical model. This offers a comprehensive search of the causes of climate changes.

***3. Ocean synthesized dataset**

An integrated dataset obtained from an ocean data assimilation system which can synthesize multiple observation data from various instrumental sources, spatially and temporally sporadic and in different quality. The synthesized product is known for its uniform and superb quality. The 4D-VAR ocean data assimilation system for the global basin in this study in particular, can provide a dynamically self-consistent dataset which is suitable for an accurate diagnosis and reliable forecast of ocean climate.

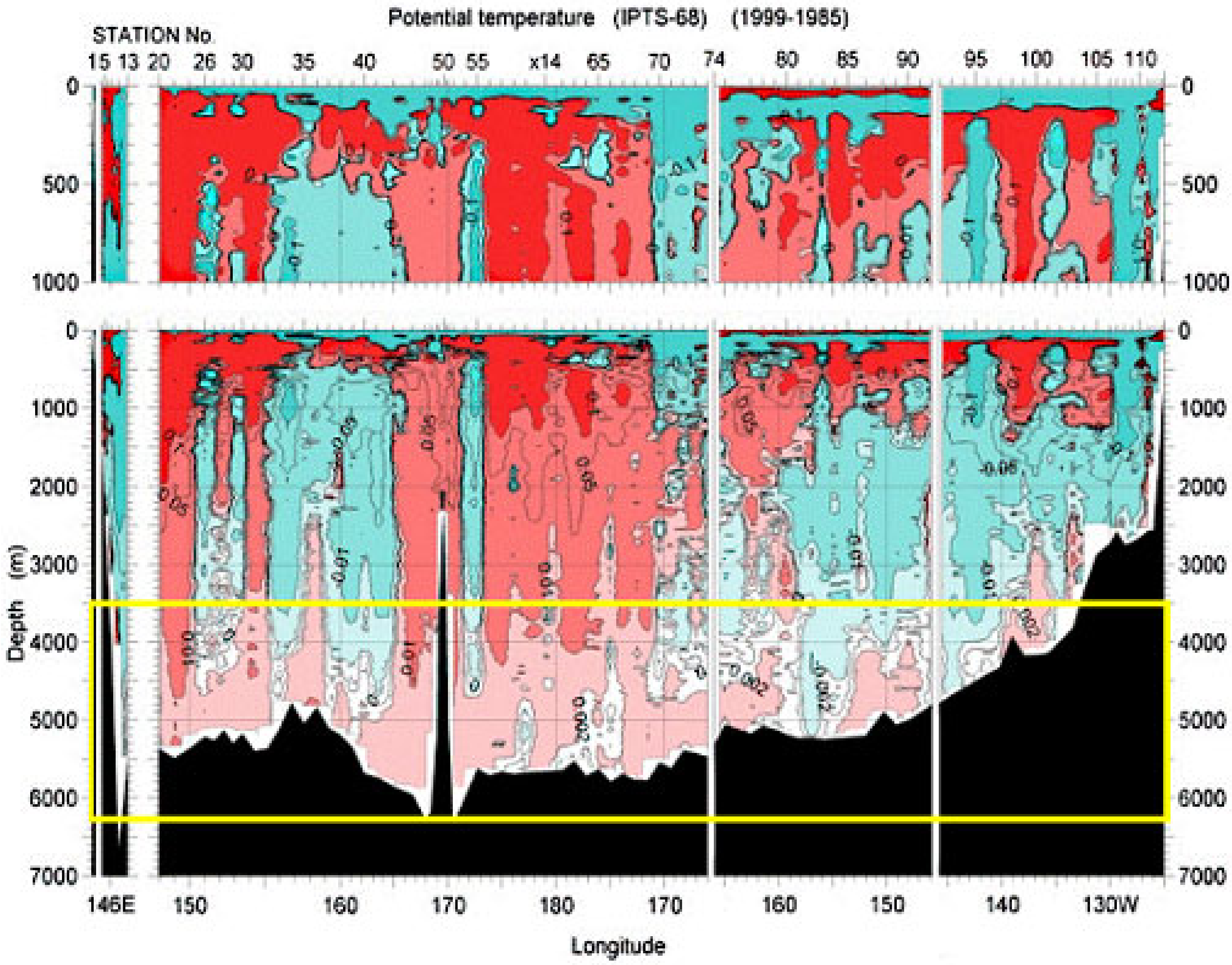

Figure 1: The difference in potential temperature obtained along 47°N in the North Pacific Ocean between 1999 and 1985. Red denotes “warming” and blue denotes “cooling. “ Significant warming is observed at depths deeper than 4,000m (area within yellow frame). Fukasawa et al. (2004)

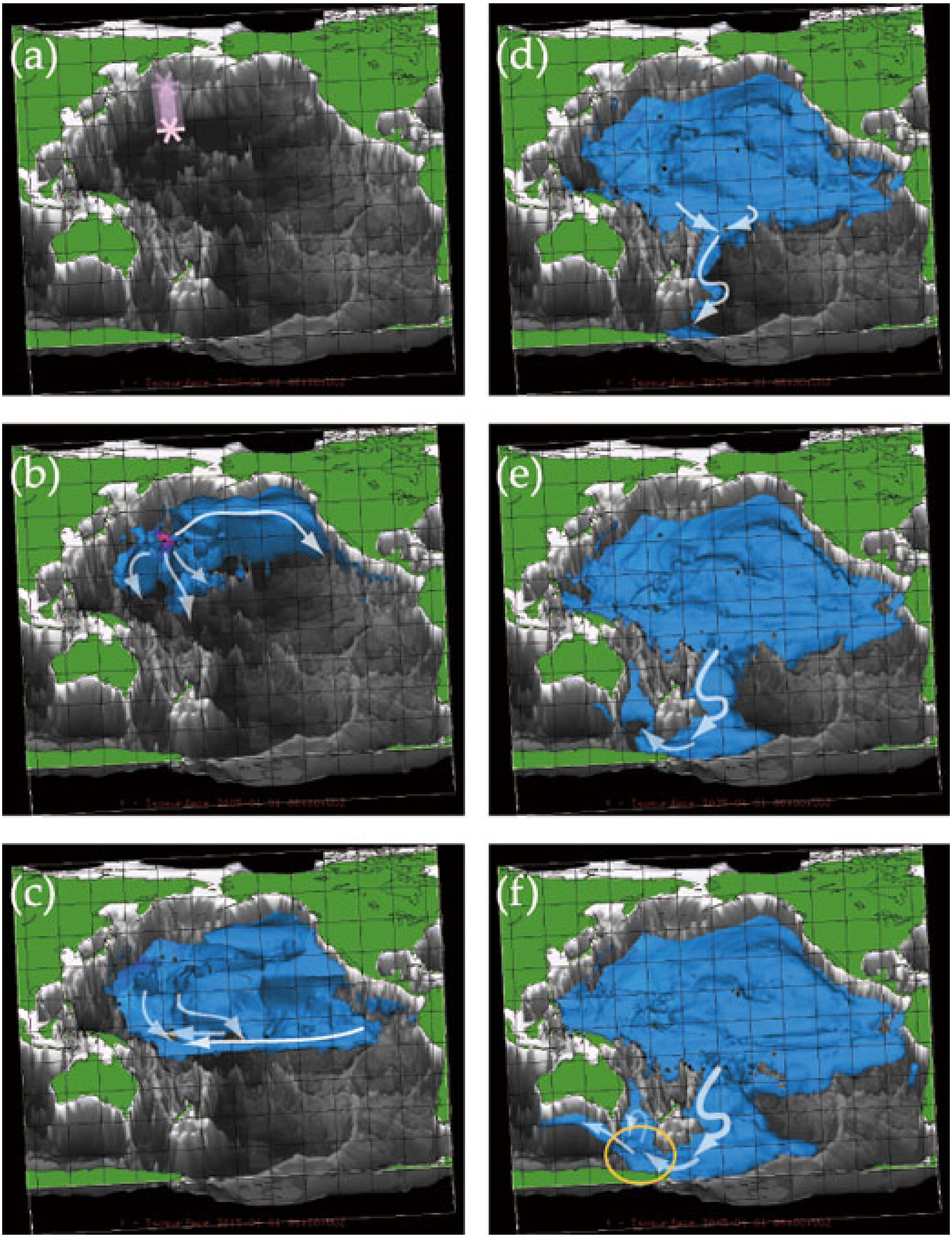

Figure 2: Bottom-water warming signal identified by adjoint sensitivity analysis
The blue areas show the propagating pathway of water temperature anomalies responsible for the bottom-water warming at 47°N-170°E (5200-m depth, marked by * in Fig. 2a) over specific time periods (0-45 years): 0-year (a), 5-year (b), 15-year(c), 25-year (d), 35-year (e), and 45-year (f) prior to the warming.
At the end of the 40-year period, the warming signal finally reaches to the upper ocean off the Adélie Coast (Fig. 2f, yellow circle).

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