Dynamical Ocean State during 1990-2006, Estimated from a 4 Dimensional Variational Data Assimilation

Shuhei Masuda[1], Toshiyuki Awaji[1,2], Nozomi Sugiura[1],
Takahiro Toyoda[1], Hiromichi Igarashi[1]
[1] Frontier Research Center for Global Change, JMSTEC, Yokohama, Japan
[2] Department of Geophysics, Kyoto University, Kyoto, Japan
Correspondence: smasuda@jamstec.go.jp

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. By using an ocean general circulation model (OGCM) and the 4-dimensional variational (4D-VAR) adjoint method, we have constructed a global ocean data assimilation system that provides a comprehensive 4-dimensional reanalysis dataset based on available observational data.

2. Data Assimilation System

The 4D-VAR data assimilation system has been constructed for the global ocean. The period covered by this reanalysis dataset is from 1990 to 2006. The OGCM used for this system is version 3 of the GFDL Modular Ocean Model [MOM; Pacanowski and Griffies, 1999].
The horizontal resolution is 1° in both latitude and longitude, with 36 vertical levels.

To generate a first guess field for the data assimilation experiment, this model was firstly executed without assimilation (hereafter referred to as the ``simulation run") by using 10-daily interannual forcings. For the surface momentum, heat and fresh water fluxes required in this simulation run, data from the 6-hourly National Centers for Environmental Prediction Department of Energy Atmospheric Model Intercomparison Project (NCEP-DOE-AMIP-2) have been used.

In our 4D-VAR approach, optimized 4-dimensional datasets are sought by minimizing a cost function [Masuda et al., 2003]. The initial conditions of model variables and air-sea fluxes (heat, fresh water, and momentum fluxes) were chosen as the control variables, with the latter air-sea fluxes modified within the assimilation period as 10-day mean values.

The assimilated elements in this study are temperature and salinity from the World Ocean Database 2001 (WOD01), FNMOC dataset and Argo floating buoys. In addition, Reynolds sea surface temperature (SST) values and sea-surface dynamic-height (SSH) anomaly data derived from TOPEX/Poseidon altimetry are used. The details of this system are described in Masuda et al. [2006].

3. Dynamical Ocean State

Figure 1 shows the longitude-time distribution of the surface zonal wind stress (Taux), SSH anomalies and SST values averaged within 2°N-2°S. The obtained reanalysis dataset shows good consistency with previous knowledge of important climate events. For example, the root mean square difference value between the observed time-evolution of Nino3 SST and the assimilated one is 0.48 K during 1990-2006, while the difference is 2.07K for the simulation run (Fig. 2).

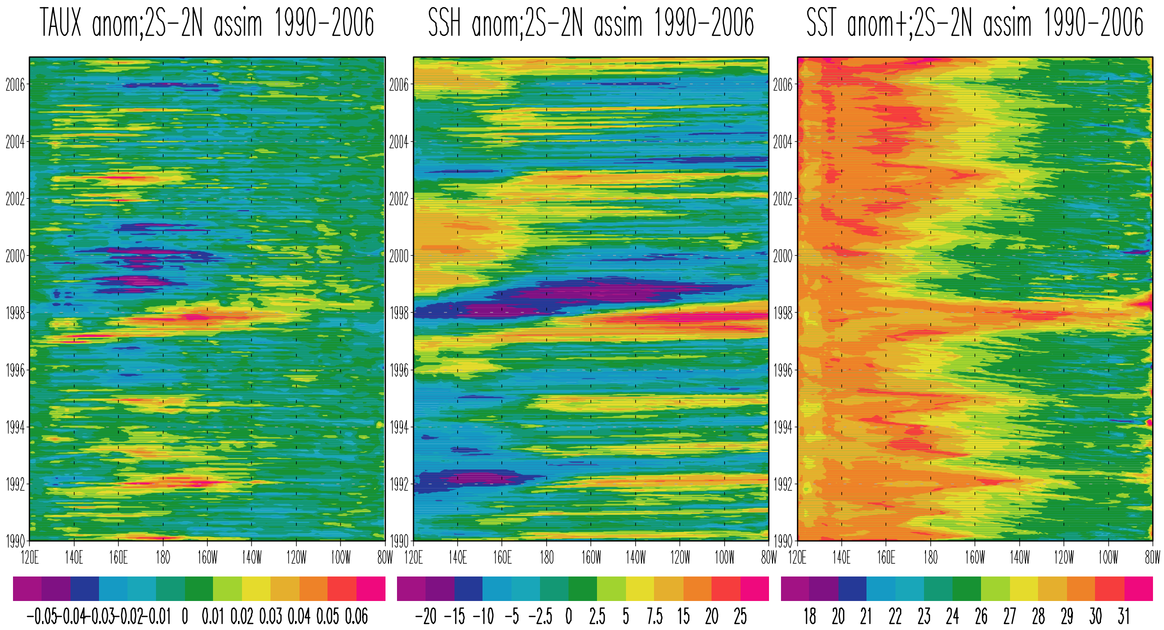

Figure 1. Time evolution of Taux, SSH anomalies and SST in the equatorial Pacific from 1990-2006.

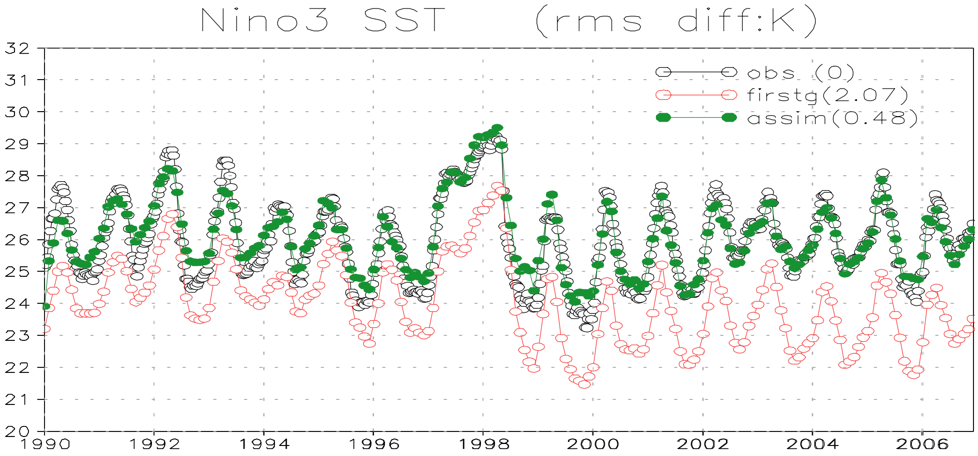

Figure 2. Time change of SST averaged in NINO3 region.

Figure 3 shows comparison of wind stress (upper panels) and wind stress curl (lower) adjusted by our assimilation experiment, with ERA40 reanalysis data for January (left-hand panels) and July (right-hand). Our dataset tends to underestimate wind stress and its curl at their middle and high values comparing with ERA40. This is the same feature as NCEP2 (the first guess field). Though detailed assessment of these reanalysis wind stress data must await future intensive observations, our estimate is not thought to be unrealistic one since it largely ranges between conventional reanalysis datasets within their error estimates.

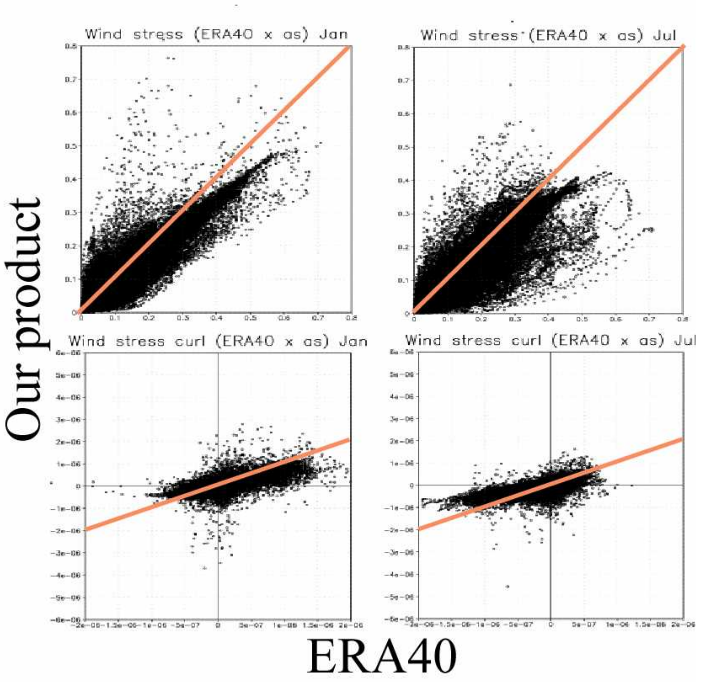

Figure 3. Scatter plot of wind stress (upper panel) and wind stress curl (lower panel) for our reanalysis dataset (vertical axis) and ERA40 dataset (horizontal).

4. Dynamical Analysis for ENSO Cycle

Our oceanic reanalysis dataset has been used to investigate the role of mass transport in the ENSO cycle. Because our product is dynamically self-consistent, this dataset provides a suitable platform for an investigation of the dynamics of the ENSO phenomena.

Figure 4 shows time-latitude plots of zonal-mean meridional mass transports estimated in the eastern equatorial Pacific. As Kug et al. [2003] show, the interannual variation of the meridional mass transport is closely related to the major ENSO events (e.g., 1991/92, 1997/98/99), a result that is basically consistent with the original recharge paradigm envisaged by Jin [1997].

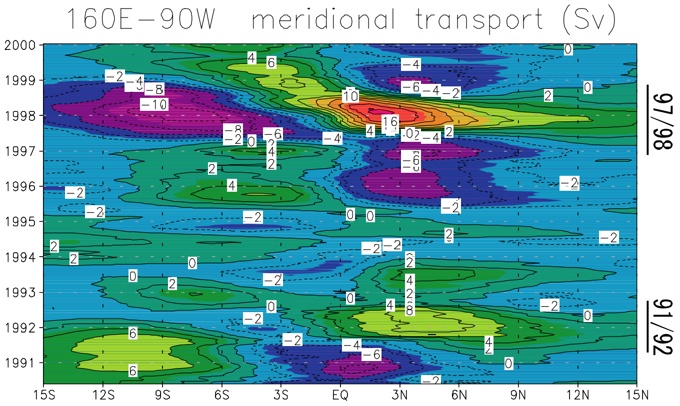

Figure 4. Time-latitude distribution of the zonal-mean meridional transport in the eastern equatorial region. Units are in *Sv*. Positive values denote northward transport.

We shall examine how the recharge-oscillator theory applies under the actual oceanic conditions encountered in the 1990-2006. Figure shows the time change of the 20^{o}C isotherm depth (as main thermocline depth: open circle) and the diagnosed one (solid) as estimated by integrating the meridional mass transport through the northern and southern walls of the whole (upper panel) and eastern (lower) equatorial region from 1990 to 2006. This result shows that, taken across the whole equatorial Pacific, the main thermocline depth changes according to recharge-discharge of water mass. However, in the eastern region, where SST value is closely related to the main thermocline depth, the time change of the main thermocline can not be solely explained by meridional mass transport. Thus, the zonal mass redistribution within the equatorial region must influence on the ENSO time evolution.

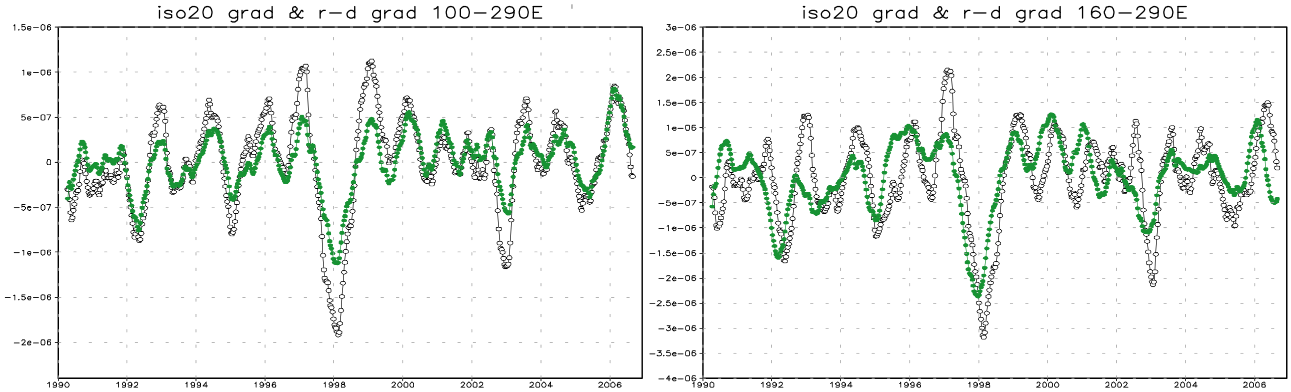

Figure 5. Time series of the local time change of the 20^{o}C isotherm depth (open circle) and that of the diagnosed 20^{o}C isotherm depth (solid circle) averaged in 5^{o}S-5^{o}N and 109^{o}E-80^{o}W (right-hand panel) , and 160^{o}E-80^{o}W (left-hand) from 1990 to 2006.

5. Deep Ocean Reanalysis Effort

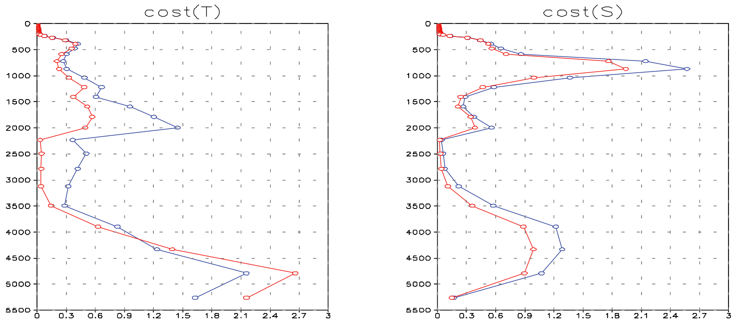

Figure 6. Cost for global averaged temperature and salinity: blue (red) curves denote the result with original (modified) parameter values.

Figure 6 shows the cost for global averaged temperature and salinity (difference between simulation and observation). We optimize vertical diffusive coefficient of the OGCM by using 'Green function method' [Menemenlis et al., 2005]. As a result, the cost is effectively reduced (from blue curves to red ones). Such a parameter adjustment is crucial for better estimate of deep ocean state.

6. Concluding Remarks

By using the 4-dimensional variational adjoint method, we have obtained an oceanic reanalysis data set for 1990-2006 including surface fluxes. The reconstructed ocean state, which is dynamically consistent, is well consistent with the previous observational studies. It is useful for understanding climate variabilities. In addition, we have done the first effort for deep ocean reanalysis experiment.

REFERENCES

Jin, F. F. 1997: An equatorial recharge paradigm for ENSO. Part I: Conceptual model, J. Atmos. Sci., **54**, 811-829.

Kug, J.-S., I.-S. Kang and S.-I. An 2003: Symmetric and antisymmetric mass exchanges between the equatorial and off equatorial Pacific associated with ENSO, J. Geophys. Res., **108**, 3284, doi:10.1029/2002JC001671.

Masuda, S., T. Awaji, N. Sugiura, Y. Ishikawa, K. Baba, K. Horiuchi and N. Komori 2003: Improved estimates of the dynamical state of the North Pacific Ocean from a 4-dimensional variational data assimilation, Geophys. Res. Lett., **30**, 1868, doi:10.1029/2003GL017604

Masuda, S., T. Awaji, N. Sugiura, T. Toyoda, Y. Ishikawa, K. Horiuchi 2006: Interannual variability of temperature inversions in the subarctic North Pacific, Geophys. Res. Lett., **33**, doi:10.1029/2006GL027865.

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

Pacanowski, R. C. and S. M. Griffies 1999: The MOM 3 Manual, Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, USA, p.680.