The role of eddy mixing in the upper ocean circulation from OFES simulation data

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1. Aim

The aim of this study is to estimate the role of eddy mixing in the basin-scale PV distribution and then quantify the extent of influence of the PV homogenization on the large-scale upper ocean circulation by using the OFES eddy-resolving simulation data.

2. Data and method

The output from an eddy-resolving model OFES is used in this study (Masumoto et al., 2004; Sasaki et al., 2004). The OFES model output was calculated by the Japanese Earth Simulator. The model is based on the Modular Ocean Model version 3, developed by the Geophysical Fluid Dynamics Laboratory/National Oceanic and Atmospheric Administration (GFDL/NOAA), and is of great significance modify the parallelization program. The computational domain covers a near-global area extending from 75°S to 75°N, with a horizontal resolution of 1/10°×1/10°, a total of 54 vertical layers, and a maximum depth of 6065 m. The data set includes horizontal velocity, vertical velocity, salinity, site temperature, zonal wind stress, meridional wind stress. In this study, we use the horizontal velocity and wind field data of the QSCAT wind field driving results of the OFES model. The time series range from January 1999 to October 2009, and the time resolution is monthly average.

To verify the results of the data analysis, the other two data sets, HYCOM (Hybrid Coordinate Ocean Model) assimilation data and SODA (Simple Ocean Data Assimilation) assimilation data are also used for comparison. The study area is North subtropical Pacific Ocean (20°N-45°N, 100°E-110°W) and North subtropical Atlantic Ocean (20°N-45°N, 82°W-0°).

3. Results

3.1. Subtropical gyre

Figure 1 shows the streamfunction of subtropical circulation. The volume transport driven by the wind stress curl is southward in both basins along 25°N in the subtropical gyre. Based on OFES, SODA and HYCOM dataset, the southward transport in the internal region driven by the wind field in the Pacific Ocean is $33.5 \pm 5.1 Sv$, $32.3 \pm 5.6\ Sv$ and $35.3 \pm 4.6\ Sv$, respectively. The southward transport of Atlantic Ocean in the internal reegion is $17.2 \pm 1.8\ Sv$, $18.2 \pm 1.9\ Sv$ and $18.4 \pm 2.6\ Sv$, respectively, which is about half of Pacific Ocean, consistent with classic wind-driven circulation theory.

In addition to the large-scale circulation pattern, we also analyze the subtropical western boundary current. Figures 2 and 3 present the vertical structure of meridional velocity along 25°N between 120°E and 126°E for Kuroshio and between 82°W and 76°W for Gulf Stream. The two western boundary currents have similar velocity and distribution characteristics. The current of the Kuroshio is narrow, with its width less than 2°. The velocity decreases with the depth rapidly, and basically disappears below 1000 m. The current of the Gulf Stream is also narrow, and it also has the characteristic of decreasing velocity with depth. In OFES and SODA model, the Gulf Stream basically disappears below 500m, while in HYCOM, the Gulf Stream has a larger meridional velocity, a wider range, a slower velocity decay with depth, and can reach a deeper depth.

3.2. Meridional overturning circulation (MOC)

The meridional velocity is averaged over the width of the ocean basin, and a vertical profile of the meridional velocity varying with latitude is obtained. There is a clear southward current deep in the subtropical North Atlantic, and there is a southward flow in the upper layer of the low latitude area south of 25° N in the two patterns of assimilation dataset of SODA and HYCOM (Figure 4). In the upper 1000 m at other latitudes, all three datasets show northward currents. The upper layer of the Atlantic Ocean transports northward and the deep layer transports southward, presenting a meridian closed circulation across the entire latitude, as known as AMOC. According to previous studies (Baringer, 2001), the northward branch of the upper AMOC flows contribute to the western boundary current.

We have done the same work for the meridional velocity in the Pacific Ocean, but we cannot see the southward transport at the deep depth and the upper northward transport, which means that there is no or very weak meridional circulation in the Pacific Ocean (Figure 5).

3.3. Time series of stream function

We also calculate the volume transport in different regions above different depths. Figure 6 shows the calculation results of OFES-QSCAT run, the left panel is the result of Pacific Ocean and the right is the Atlantic Ocean. From top to bottom, we respectively present the transport of full water depth across the width of the entire ocean basin, the transport of west boundary current, inner zone southward transport, and the entire 1500m upper ocean basin along 25°N. It can be seen from Figure 6a and 6e that in the OFES model, the north-south volume transport satisfies the conservation of mass, and the subtropical western boundary current flows in the Pacific and Atlantic are roughly quite different. The Kuroshio current is slightly larger, while the Gulf Stream flow is found to have a decreasing trend (Figure 6b and 6f). The southward transport in the internal region is in balance with the northward transport of the western boundary current (Figure 6c and 6g), and the south transport of inner zone also shows the decreasing trend. The transport of the upper 1500 m along 25°N is very different in the two basins. The net flow of Pacific at the upper 1500 m is almost zero, which means that the Pacific is also conserved in mass in the upper ocean. And that result is coherent with section 3.2 that there is no meridional circulation in the Pacific Ocean. On the contrary, the calculation of the transport of the Atlantic Ocean at the upper 1500 m shows approximately $11\,Sv$ northward net transportation, which is probably related to the upper branch of AMOC.

The linkage between the west boundary current and subtropical gyre can be explained by meridional overturning circulation. The northward branch of AMOC is directly compensated at the western boundary in the upper layer, thereby increasing the transport of the western boundary current. The volume of the subtropical circulation is conserved in the north-south direction in the upper ocean. The calculation result of the upper 1500 m is mainly contributed by AMOC. This net transport is calculated as the transport of AMOC and added to the transport of the wind-driven circulation to obtain the transport of the Gulf Stream, which is approximately equivalent to that of Kuroshio. This can explain why the flow of the Kuroshio should be twice that of the Gulf Stream in the classic wind-driven circulation theory, and the two are indeed equivalent in the observed.

4. publication/conference presentation

This study has been written as a manuscript. We plan to submit to the manuscript to "Journal of Marine Science and Engineering" shortly.

5. perspectives in future

The results of this study have shown the importance of MOC on the transport of the west boundary current. We will continue analyzing the OFES data and find the role of eddy mixing on the variability of the Kuroshio and Gulf Stream.

6. Figures:

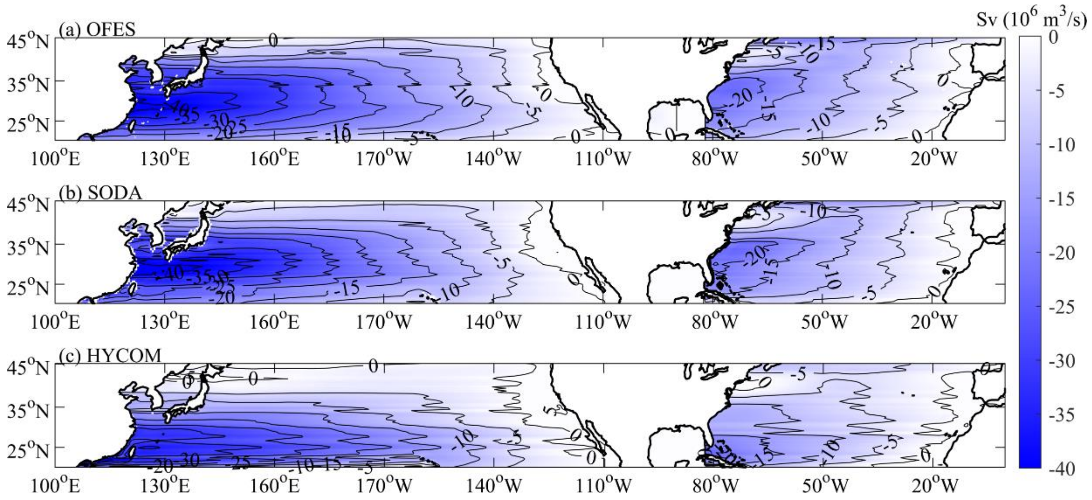

Figure 1. Maps of streamfunction calculated by equation (4) based on (a) OFES-QSCAT run, (b) SODA dataset, and (c) HYCOM dataset.

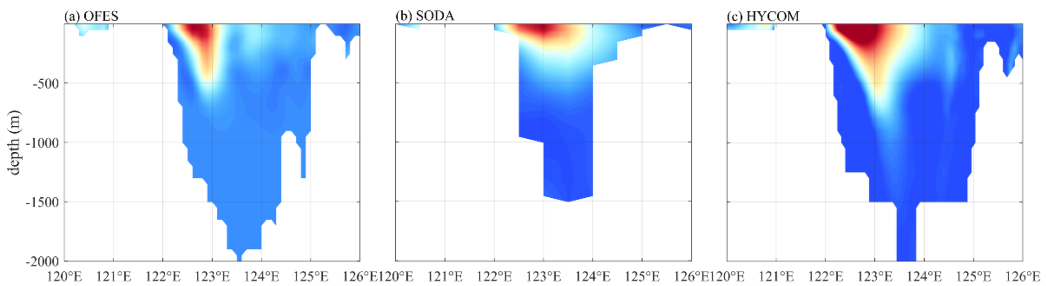

Figure 2. Meridional velocity of Kuroshio between 120°E and 126°E along 25° N based on (a) OFES-QSCAT run, (b) SODA dataset, and (c) HYCOM dataset.

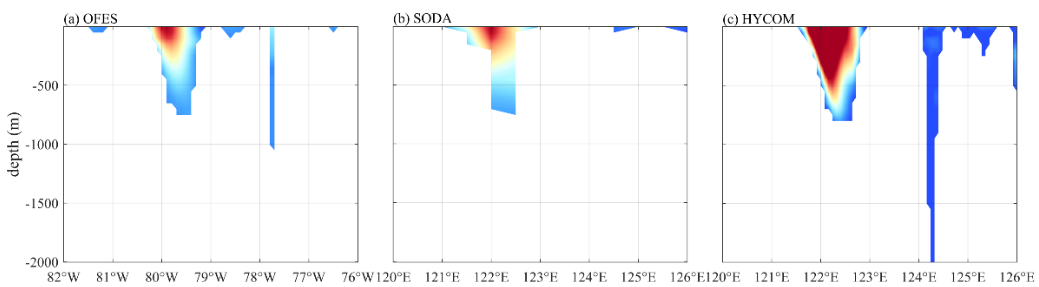

Figure 3. Meridional velocity of Gulf Stream between 82°W and 76°W along 25° N based on (a) OFES-QSCAT run, (b) SODA dataset, and (c) HYCOM dataset.

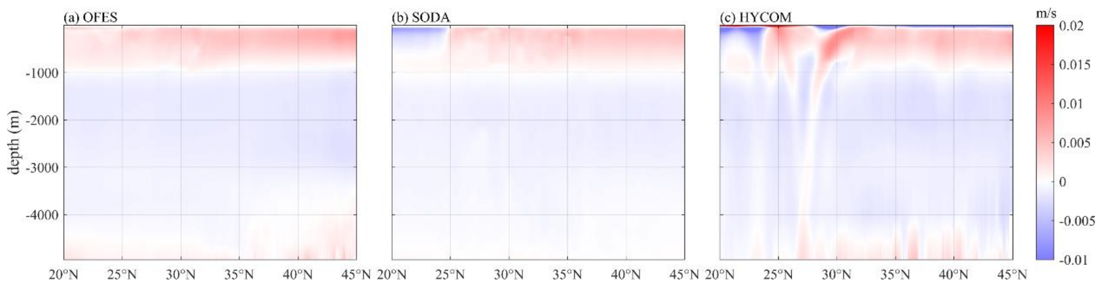

Figure 4. The vertical distribution of the mean meridional velocity over the width of the Atlantic Ocean basin based on (a) OFES-QSCAT run, (b) SODA dataset, and (c) HYCOM dataset.

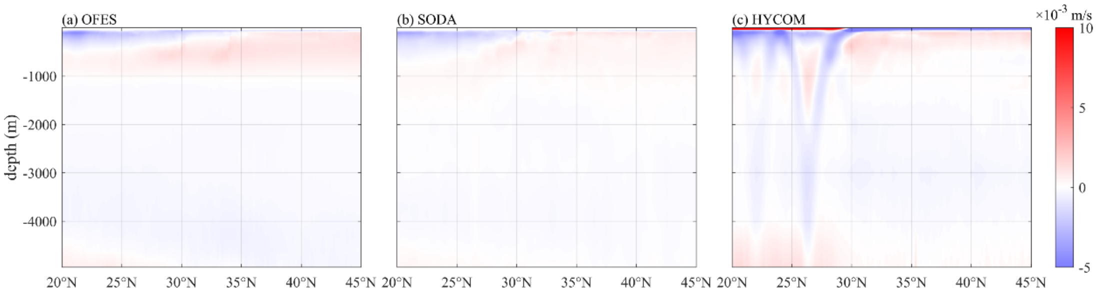

Figure 5. The vertical distribution of the mean meridional velocity over the width of the Pacific Ocean basin based on (a) OFES-QSCAT run, (b) SODA dataset, and (c) HYCOM dataset.

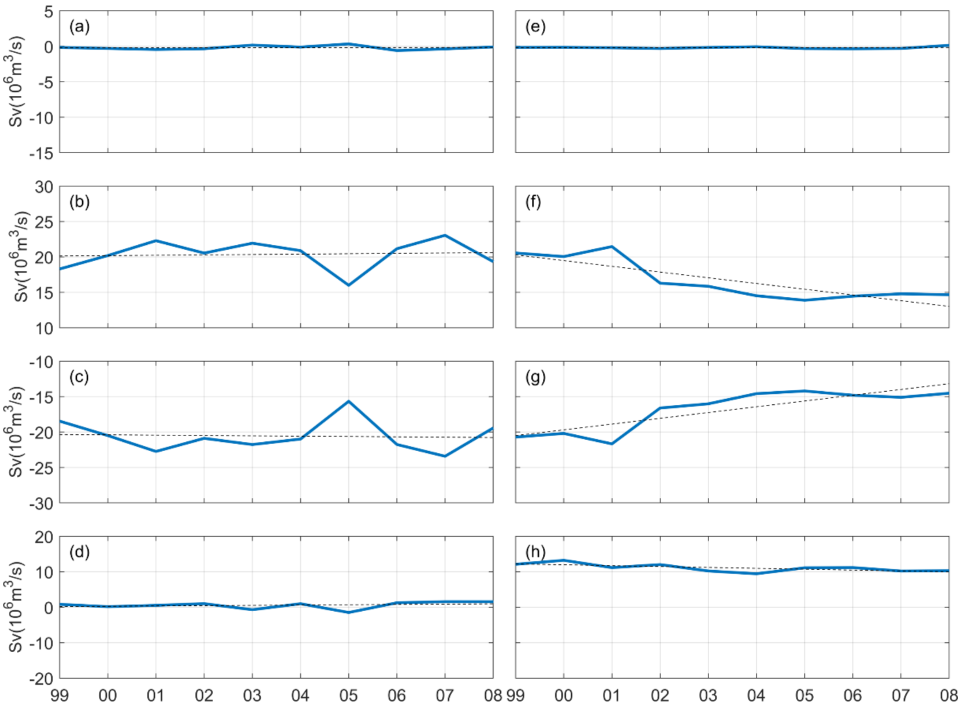

Figure 6. The transports calculated by the OFES-QSCAT run is the Pacific Ocean on the left and the Atlantic Ocean on the right. From top to bottom, it represents the flow of the entire layer along the basin width of the 25°N, the transports of the boundary flow, the flow of the inner zone and the transports of the upper 1500 m.