Title: Roles of eddy mixing on the large-scale circulation

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Results:

In this study, the Massachusetts Institute of Technology general circulation model (MITgcm, Marshall et al. 1997a; 1997b) is employed to solve the 3D Boussinesq primitive equations. Motivated by the simulation of Cox (1985, called C1985 after), we build up a rectangular basin extending 60 degrees in both longitude and latitude, and its four boundaries are all no-slip solid boundaries, with the southern boundary being on the equator. The bottom of the basin is constantly 4000 m deep, except for a simple continental shelf, whose depth increasing from 200 m to 4000 m in 4 degrees, is assembled along the western boundary. To avoid introducing complicated topographic effects on the pattern of the upper circulation, we use a straight western boundary rather than the land mass in C1985. The vertical structure of the basin is described by 29 layers with non-uniform thickness from 10 m at the surface to 500 m in the deep.

Salinity in the model is constant 35, and the equation of state is linear. Then the density is only controlled by temperature and described as

$$\rho = \rho_0 + \rho_{ref}[-\alpha_T(T - T_0)]$$

where $\rho_0 = 25\,kg \cdot m^{-3}$, $\rho_{ref} = 1000\,kg \cdot m^{-3}$, $\alpha_T = 2 \times 10^{-4}\,°C^{-1}$, and $T_0 = 20\,°C$. The model is driven at the surface by zonally uniform wind stress τ^x (similar to that used by C1985) and density restoration ρ^*, given by

$$\rho^* = \begin{cases} 23 + \dfrac{3y}{36°N}, & y \le 36°N, \\ 27 + \dfrac{y - 36°N}{24°N}, & 36°N < y \le 60°N. \end{cases}$$

The restoration time scale for the surface density is 40 days, which means the restoration coefficient γ is taken to be $0.4\,m \cdot day^{-1}$ in the top layer (10 m). The solid line in Fig. 1(a) means the wind employed in the control experiments, and the other four profiles are used in the sensitivity experiments to diagnose the strength of the EUC. A density jump at 36ºN aligns with the maximum eastward wind.

Three horizontal resolutions of 1º, 0.3125º (called 0.3º after), and 0.1º are selected to represent the non-eddy, eddy-permitting, and eddy-resolving simulations, respectively. For 1º case, horizontal dissipation is provided by a Laplacian viscosity ($A_{H1} = 10^4\,m^2 \cdot s^{-1}$). The biharmonic viscosity by modified Leith scheme (Fox-Kemper and Menemenlis, 2008) is used in 0.3º and 0.1º cases. In addition, the vertical viscosity is set to $10^{-4}\,m^2 \cdot s^{-1}$, and diapycnal diffusivity is $10^{-7}\,m^2 \cdot s^{-1}$.

The 1º model is initialized by the vertical stratification derived from World Ocean Atlas 2013 and run for 250 years to reach an equilibrium solution. From this point, the 1º, 0.3º, and 0.1º models are run for another 50 years, and the results in the last 20 years are used for the following analysis.

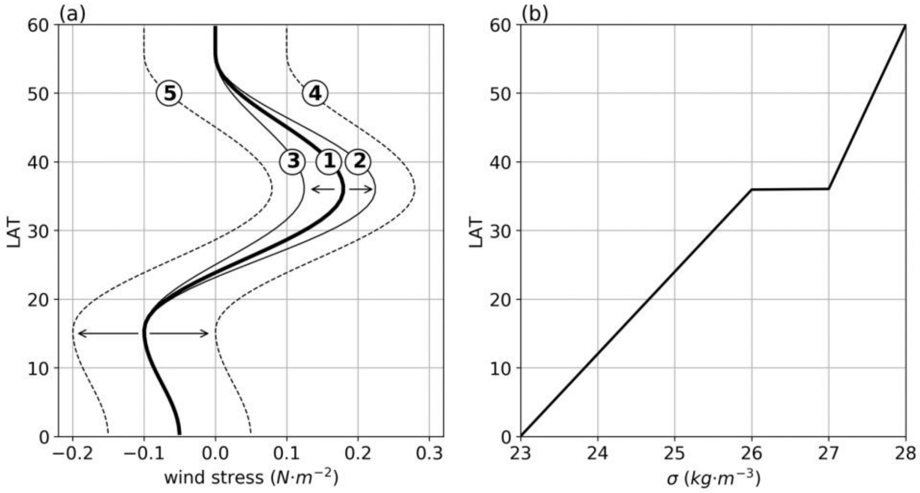

Fig. 1 The model forcing conditions: (a) zonal wind stress and (b) restoring surface density. The thick solid line (profile 1) in (a) represents the wind stress used in the control experiment, and the other four varying wind profiles are employed in sensitivity experiments to explore the strength of EUC. Profiles 2 and 3 vary the subtropical wind stress curl, and profiles 4 and 5 vary the tropical wind strength. A density jump at 36ºN aligns with the maximum eastward wind.

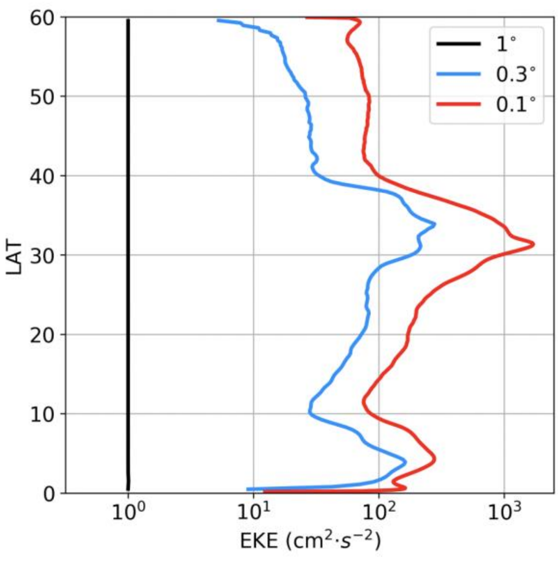

Fig. 2 Zonal-averaged EKE for 1º, 0.3º, and 0.1º models. The EKE is an order of magnitude greater when the resolution increases from 0.3º to 0.1º.

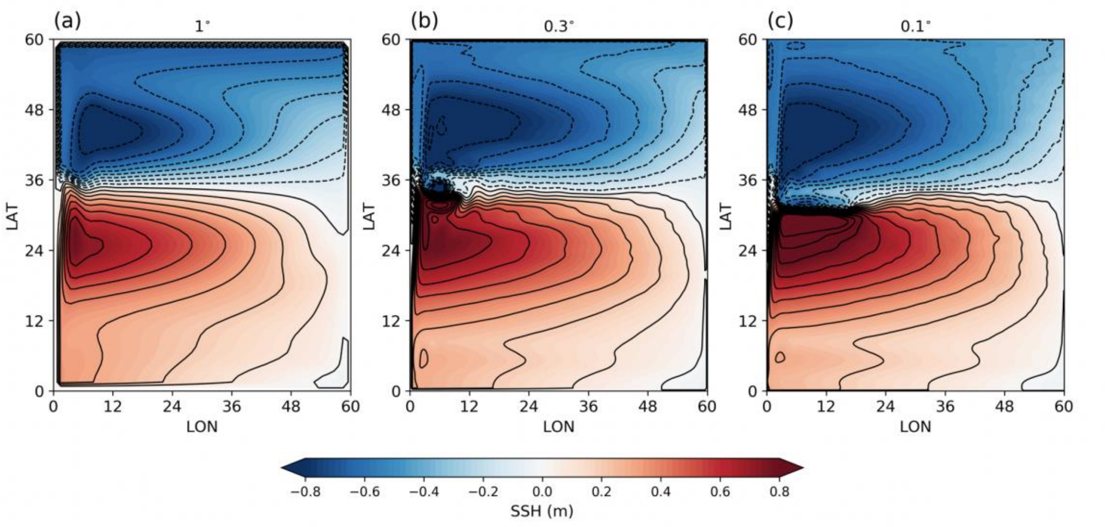

Fig. 3 Sea surface height for (a) 1º, (b) 0.3º, and (c) 0.1º models from the control experiment. With increasing resolution, the maximum depth of the thermocline is seen to move from the subtropical interior toward the outcrop region.

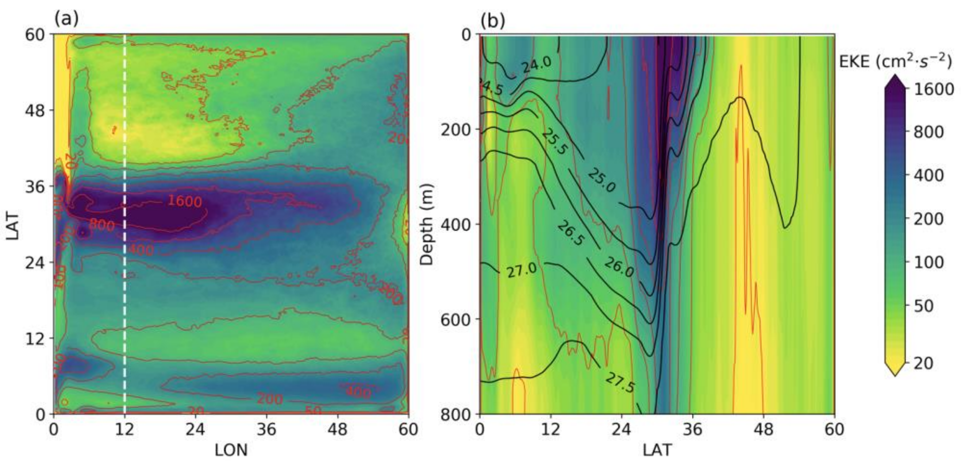

Fig.4 (a) EKE map for 0.1º model. (b) EKE (colors) and isopycnals (black contours) along a meridional section marked by the white dashed line in (a).

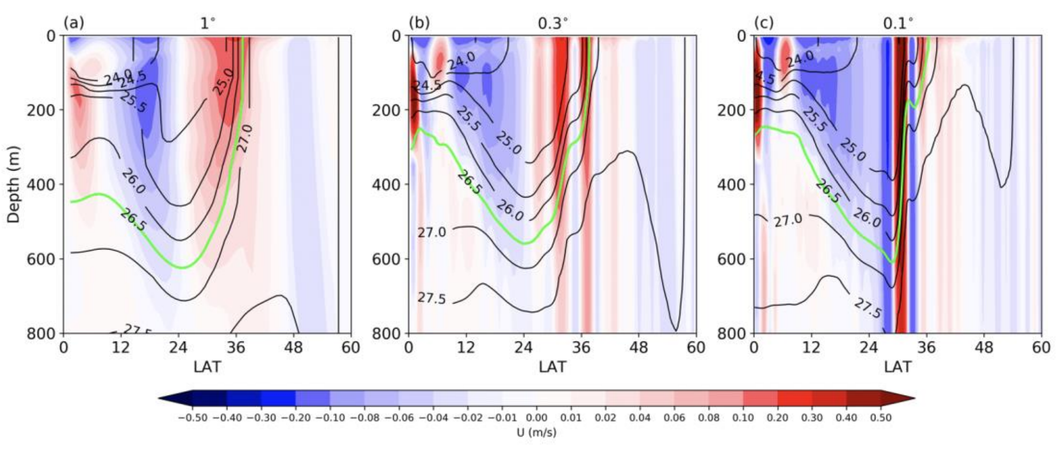

Fig. 5 Isopycnals (black contours) and zonal velocity (colors) along the section of 12ºE for (a) 1º, (b) 0.3º, and (c) 0.1º models. The 26.5 isopycnal (green line) is taken to be the main theromocline.

Perspectives in future:

To diagnostic the PV balance in the upper ocean based on the model output.