Climate Modeling

(GCM : General Circulation Model)

A Numerical Study on the Throughflow in the Indonesian Seas

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1. Introduction

The interbasin mass exchange between the Pacific and Indian Oceans through the Indonesian seas is believed to play a crucial role not only in the global ocean thermohaline circulation (Broecker, 1991) but also in the warm water pool formation in the western tropical Pacific. There have been several attempts to estimate the transport of the throughflow by using a variety of indirect methods and numerical models since the 1960s (e.g., Wyrtki, 1961; Gordon, 1986; Semtner and Chervin, 1988; Hirst and Godfley, 1993). Those estimates indicated a wide range of the net throughflow transport that spans from a negligible value to 16Sv (1 Sv = 10^6 m^3/s). Although the above studies provide us a important information about a total transport between the Asian and the Australian continents, none of them shows detailed flow pattern and the transport through each passage located in the Indonesian archipelago. Only one direct measurement at the Lombok Strait has been done by Murray and Arief (1988), and they reported the 1985 annual mean transport of 1.7 Sv, with a seasonal root-mean-square deviation of 1.2 Sv.

It is well-known fact that the circulation in the Indonesian seas is strongly affected by the Asian and Australian monsoons. Wyrtki (1961) indicated the seasonal reversal of many surface currents in the Indonesian seas by use of comprehensive ship drifts dataset. Recently, Masumoto and Yamagata (1993) confirmed this point by using a fine resolution oceanic general circulation model (OGCM) and demonstrated that the model could predict successfully the observed transport through the Lombok Strait. Their model, however, does not permit the net barotropic throughflow between the Pacific and Indian oceans. In case of the model with the net interbasin transport, therefore, it is of interest to know if the transport flows through the Timor Sea or not. In order to clarify the mechanism that determine the mass and heat transport of the Indonesian throughflow, it is important to understand the effect of a complex geometry in the Indonesian archipelago and of the interactions between the net throughflow and a local circulation driven by the monsoon winds.

In this study, we try to simulate the detailed seasonal circulation in the Indonesian sea region by using a fine resolution OGCM which can take the major passages and the net barotropic throughflow into account, and try to understand the interactions between them and the monsoonal circulation.

2. Model

The ocean model used in this study is based on the Cox code OGCM developed in the Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration (GFDL/NOAA) (Cox, 1984). The domain covers the Pacific and Indian oceans between 50°S and 30°N (Figure 1). It should be noted that the whole Australian continent is included in this model. The horizontal resolution is 0.5° in both latitude and longitude. There are 20 levels in the vertical, with a 10m resolution near the surface. Since resolving the complex geometry in the Indonesian seas could be a critical issue, fine resolution topographic data are fitted into the model as accurately as possible within limitation of lateral and vertical model resolution (see Figure 2).

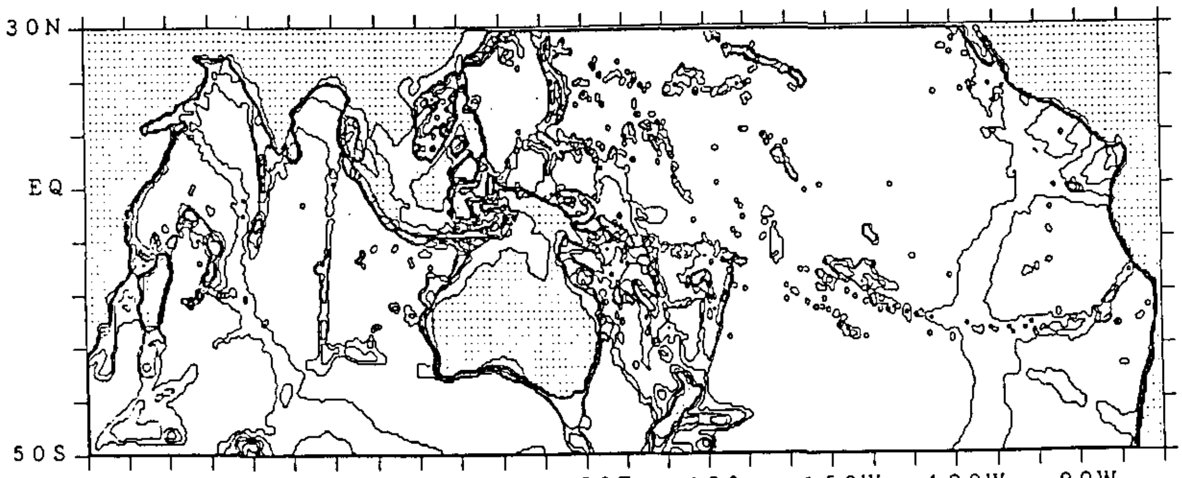

Figure 1 : Model geometry with bottom topography. Contours are 200, 500, 1000, 2000, 3000m depth.

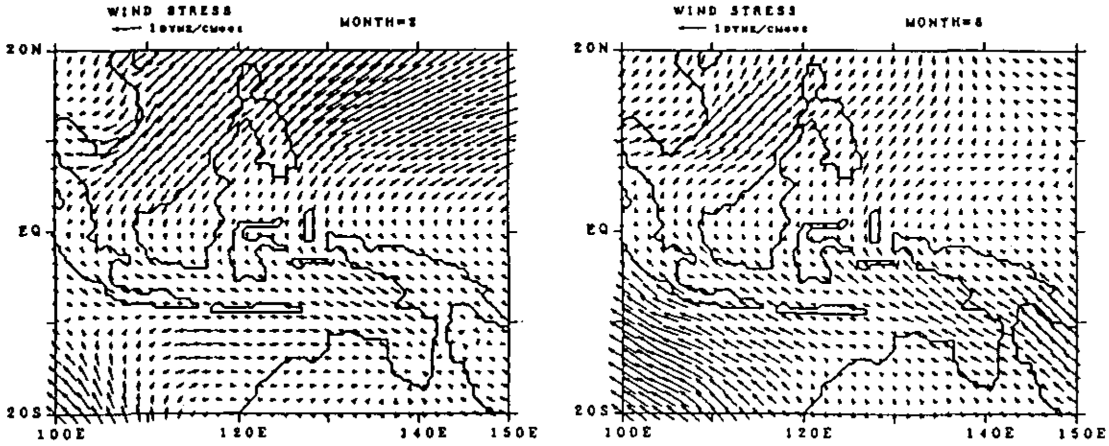

Figure 2 : Wind stress vectors on February and August after Helloerman and Rosenstein (1983).

Values assigned to the lateral eddy viscosity and diffusivity are 2×10^7 and 1×10^7 cm^2/s, respectively. Near the northern and southern boundaries (poleward of 27°N and 47°S), those values increase to become 20 times lager than the inner ones within the sponge layer. Temperatures are restored to the annual mean climatology of Levitus (1982) within the same sponge layer, with a minimum time scale of 2 days at the boundaries. All those measures are taken in order to ease the artificial wall effects. The vertical eddy viscosity and diffusivity are based on the formulae given by Pacanowski and Philander (1981).

The net heat flux (Q) is parameterized by

$$Q(T) = Qc + \partial Q/\partial T\ (T - Tc)$$

where T is the sea surface temperature, Qc is the observed heat flux at the climatological sea surface temperature (Tc), and $\partial Q/\partial T$ is a local feedback parameter. Variables Qc, Tc, and $\partial Q/\partial T$ are calculated

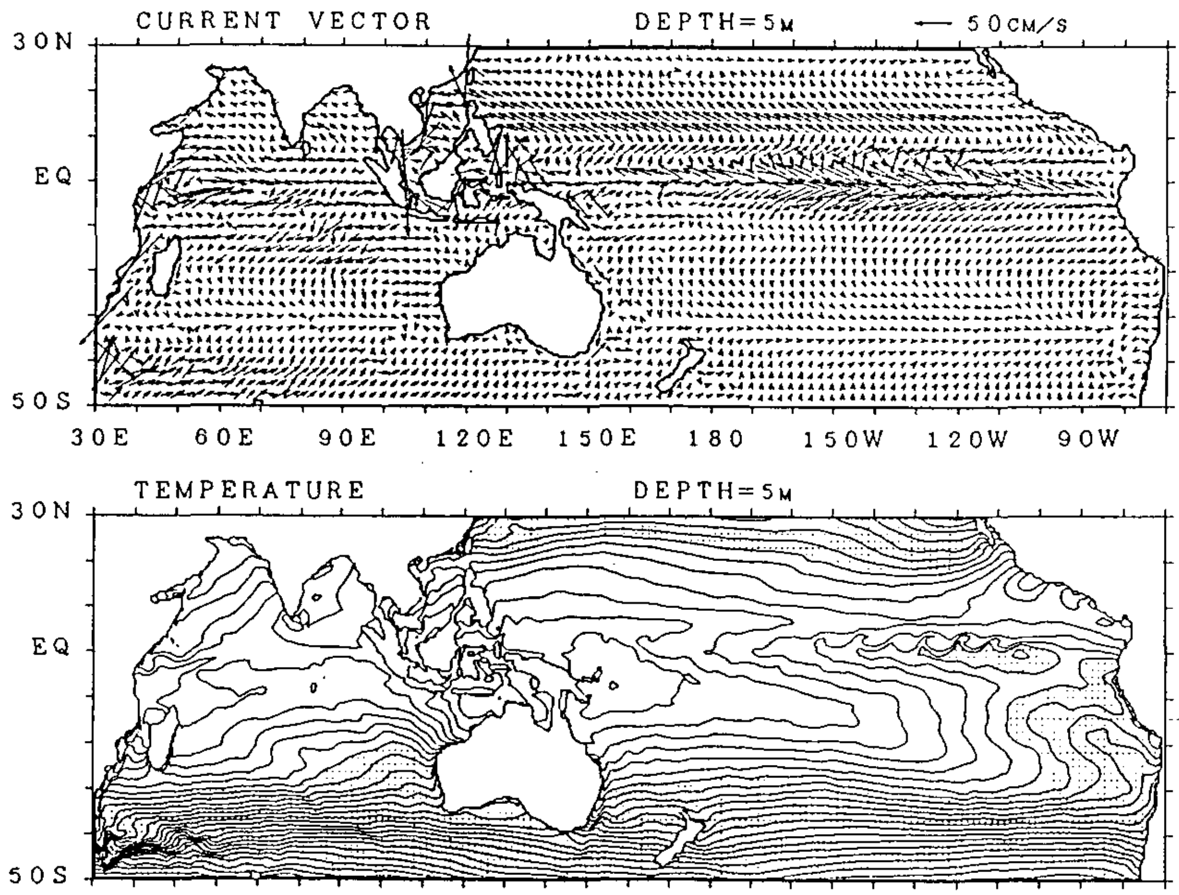

Figure 3 : (a) Current velocity vectors and (b) temperature fields at a depth of 5m on December 15. Contour interval is 1°C. The regions less than 24°C are shaded.

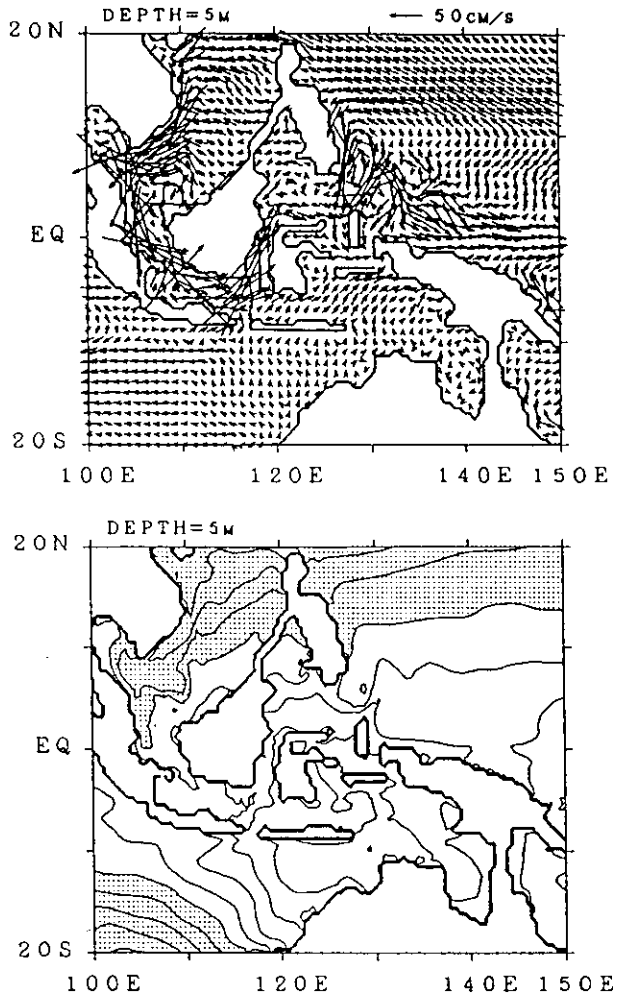

Figure 4 : Same as in Figure 3, but for the Indonesian archipelago. The regions less than 28°C are shaded.

by Oberhuber (1988). Since the Oberhuber flux data are very sparse in the region south of 30°S, the Esbensen and Kushnir (1981) flux data are smoothly combined with it for Tc and Qc. We assumed a constant value of -35 W/m^2/°C for $\partial Q/\partial T$ in the same region. The initial condition is annual mean temperature field (Levitus, 1982) with no motion. The model is forced by the monthly mean climatology wind stress of Hellerman and Rosenstein (1983) multiplied by 0.75. The factor 0.75 is based on the recommendation of Tropical Ocean-Global Atmosphere (TOGA) Numerical Experimental Group. The highly monsoonal winds over the Indonesian seas are shown in Figure 2.

3. Results

Here we show only the preliminary results for the end of the model first year. Figure 3 shows the current and temperature fields at a depth of 5m for the end of the first year. It should be noted that, although the model does not reach to the dynamically and thermodynamically equilibrium state, the surface circulation is very closely resemble to the observed one. In particular, the Legeckis waves, which are generated by the shear instability associated with the strong equatorial current system, are clearly shown in the eastern equatorial Pacific.

Enlarged maps of the current and temperature fields in the Indonesian seas are shown in Figure 4. The North Equatorial Current (NEC) flows to the west at around 14°N and bifurcates to the north and the south at the Philippine coast. Most of the southward Mindanao Current (MC) deflects to the east and generates a cyclonic circulation off Mindanao island. Some of the MC flows into the Celebes Sea. Strong surface eastward flow through the Java Sea deflects to the north and penetrates into the Macassar Strait at this time of the year. Weak northward flows in the Lombok Strait and the Timor Sea suggest that the throughflow transport would be very weak in the boreal winter, since the transport is confined within the upper few hundred meter depth (Wyrtki, 1987; Murray and Arief, 1988). The North Equatorial Countercurrent (NECC) is not clearly shown in Figure 4. The New Guinea Coastal Current bigins to flow southeastward along the Irian Jaya/Papua New Guinea coast associated with the northwesterly monsoonal wind (Masumoto and Yamagata, 1991). These surface flow fields are consistent with the charts provided by Wyrtki (1961).

Practically, the model has to be driven at least for 4 or 5 years to reach a dynamically equilibrium state in the tropical region, although the barotropic flow field spins up within few months Further integration of the numerical model is now under way.

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