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# Oceanographic conditions in Pelabuhanratu Bay, west Java

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**Abstract:** In December 1994 and August 1995, field observations by STD were carried out from sea surface to 200m depth in Pelabuhanratu Bay, which is a small bay located at the southern coast of west Java, facing to the Indian Ocean. Remarkable difference between both months was found in temperature and salinity profiles, that is, remarkable seasonal variations. Compared with August, higher temperature and lower salinity water occupied near the sea surface in December. In subsurface layer, the temperature in December is 2 to 5 ℃ higher than that in August through the water column of 200m, and the salinity in December is lower from the surface to about 80m depth than that in August, but higher below about 80m depth. The density stratification is affected by salinity near the sea surface, but below 80m depth by the temperature. In the observations in August, the spatial variations of the thermocline depth existed along the section of the bay axis, but it cannot be confirmed whether or not the internal waves occurred. In addition, the occurrence of coastal upwelling is not confirmed for the internal radius of deformation larger than the bay length.

## 1. Introduction

Detailed observations in the western tropical Pacific Ocean, especially Indonesian area, are required to detect long-term variations in related to El-Nino Southern Oscillation (ENSO) and/or Indonesian Throughflow (e.g., GORDON, 1986: BROECKER, 1991; YAMAGATA and MASUMOTO, 1989; WEBSTER and LUKAS, 1982; LUKAS *et al.*, 1996). But, few observations have been made in the Indonesian coastal regions.

Oceanographic observations were carried out in Pelabuhanratu Bay as a cooperative study between Tokyo University of Fisheries and Bogor Agricultural University (called IPB). Pelabuhanratu Bay is a small bay, located at the southern coast of west Java, facing to the Indian Ocean (Fig. 1), and the bay length and width are about 20 km and 18 km, respectively. The detailed bottom topography in the bay cannot be taken. Field study was made in December 1994 and in August 1995 to clarify the oceanographic condition, especially the stratification, in Pelabuhanratu Bay.

The oceanographic studies in Pelabuhanratu Bay have been made by the IPB stuff (ATMADIPOERA *et al.*, 1994). They suggested that the surface water circulation is influenced by north west monsoon in summer in the southern hemisphere and the water properties at the sea surface near the coast are affected by the river discharge. PURBA *et al.* (1993) tried to analyze the coastal upwelling in south of west Java waters induced by southeast monsoon during the period from July to September, using surface temperature image, BT and hydrocast data obtained at standard depths. They indicated less variations of physical properties from July to August, and found an evidence of the upwelling in the subsurface layer under the surface homogeneous layer in September.

Both studies suggest that (1) the oceanographic condition in this area is significantly affected by northwest or southeast monsoon, and (2) the detailed vertical distributions of temperature and salinity are required to fully understand it. Then, we made a plan to measure temperature and salinity distributions by using STD, produced by Allec Company (ASTD).

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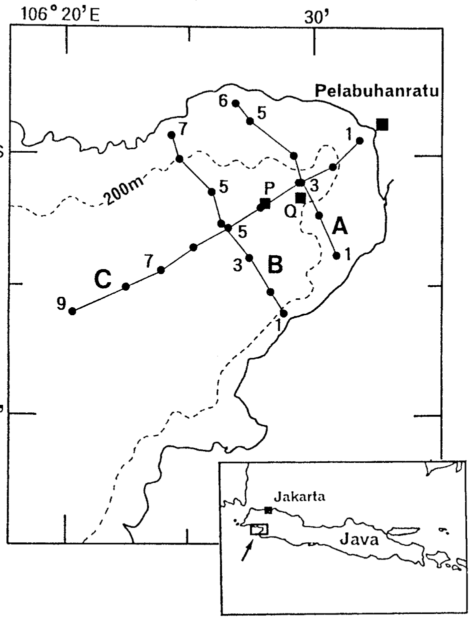


Fig. 1. Bottom topography of Pelabuhanratu Bay and location of STD stations. Stations were made in August 1995 except for Stns. P and Q in December 1994.

## 2. Observations

The observations were made on December 22, 1994, and during the period from August 12 to 14, 1995. The former was preliminary observation for the latter. The locations of ASTD stations are shown in Fig. 1. In this study, temperature and salinity data at each depth, digital values by ASTD measurements, were obtained in the range from the sea surface to 200m depth at 0.2 m interval.

## 3. Results

### *3-1 Results in December, 1994*

Figures 2a and 2b show vertical profiles of temperature and salinity at Stns. P and Q (see Fig. 1) in December 22, 1994. The vertical profiles at both stations are similar to each other. The sea surface temperature is very high (about 28.6℃). The temperature gradually decreases from the sea surface to 90 m depth with weak gradient and the strong thermocline exists directly below this depth. Even at 90m depth, the temperature is 27.5℃ but fall to 12 ℃ at 200m depth, so the temperature difference between 90 m and 200 m depths reaches 14.5℃.

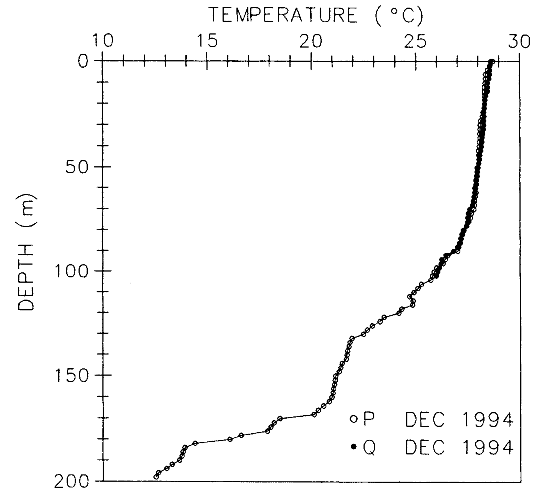


Fig. 2a. Temperature profiles observed in December 1994.

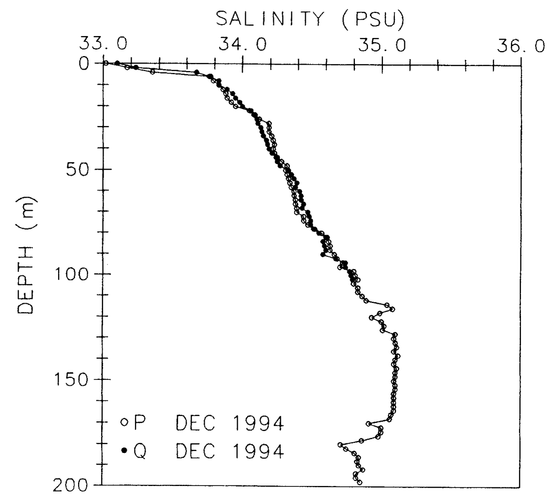


Fig. 2b. Same as Fig. 2a except salinity.

The salinity is very low (33.10 psu) at the sea surface for rainy season, but abruptly increases from the surface to 130 m depth (35.08 psu). The salinity shows maximum between 130 m and 160 m depths and tends to decrease below the maximum.

### *3-2 Results of August, 1995*

The observations were made by ASTD along three lines, A to C (see Fig. 1) during the period from August 12 to 14, 1995. The ASTD observations on Lines A and B crossing the bay were carried out down to near bottom or to 100

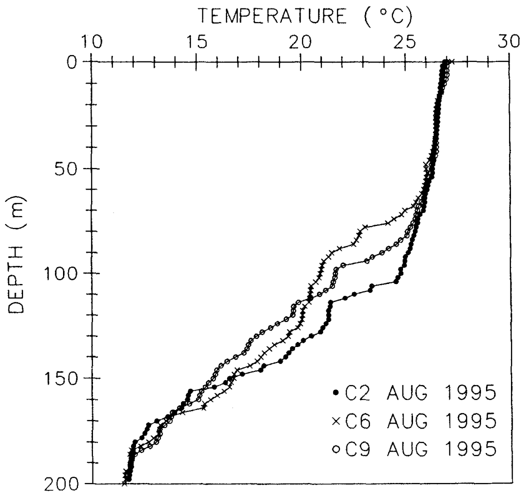


Fig. 3. Temperature profiles observed in August 1995.

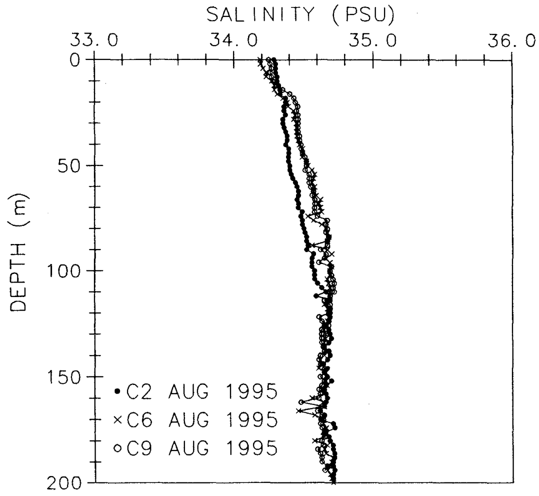


Fig. 4. Same as Fig. 3 except salinity.

m depth except Stn. B2 ; also the observation along the bay axis, Line C was carried out from the sea surface to 200 m depth except for Stn. C1 with the bottom depth of 150 m.

Figure 3 shows typical vertical profiles of temperature at three stations, C2, C6 and C9, corresponding to the stations of the head, center and mouth of the bay, respectively (see Fig. 1). The sea surface temperatures are almost the same, about 27℃ at three stations. The temperature profiles are seen to be composed of the weak and strong stratified layers. Thickness of the upper layer with weak stratification is about 60 m at Stn. C6, 80 m at Stn. C9, but 100 m at Stn. C2. The temperature difference between the top and bottom of the layer is only 1.0℃ to 2.0℃. The strong stratified layer, i.e., thermocline, is formed from the bottom of the weak stratified layer to 190 m depth. This temperature difference between the top and bottom of the thermocline reaches about 14℃ for depth range of only 100 m. The thermocline depth at Stn. C6 is shallower than that at Stn. C2. Though temperatures at the thermocline depths are slightly different among three stations, the temperature at 190 m depth is about 11.7℃, common to these stations. The strong stratification and shallow thermocline is well known as a typical thermal structure in tropical region (e.g., PICKARD and EMERY 1990).

The salinity at the sea surface is the lowest in the vertical distributions and ranges from 34.2 to 34.3 psu (Fig. 4). The salinity gradually increases with depth in the surface layer (above about 100 m depth), corresponding to the weak temperature gradient (Fig. 3). The salinity in this layer is lower at Stn. C2, located near the bay head, than at other stations. In the thermocline, the salinity is less variable and ranges between 34.6 and 34.7 psu. However, such a high salinity as around 35.0 psu observed in December 1994 (Fig. 2) is not found in these profiles.

Figures 5 and 6 show the temperature and salinity distributions along Lines A and B, transverse sections of the bay (Fig. 1), respectively. For the observation by a small boat, the maximum depth for measurement was restricted within 100 m except Stn. B2. As speculated from Figs. 3 and 4, the vertical variations of temperature and salinity are very small above 100 m depth. Though the horizontal temperature and salinity gradients slightly exist, a remarkable density current cannot be expected for weak horizontal gradient. Near the sea surface, i.e., above 10 m depth, Line A has higher temperature and lower salinity than Line B. Line A is nearer the bay head than Line B and is more affected by the fresh water discharge from rivers.

Figure 7 shows the vertical temperature distribution along Line C, the bay-axis (Fig. 1).

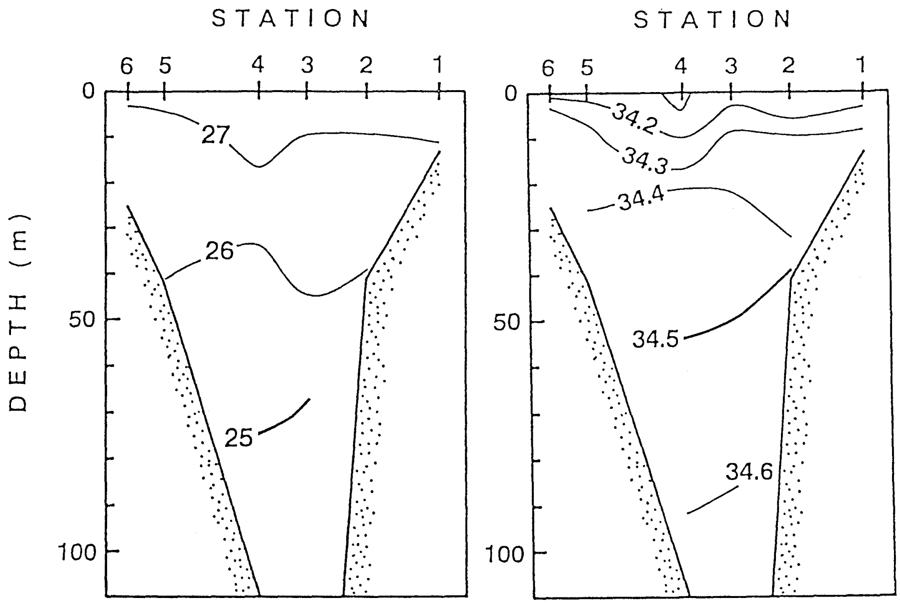


Fig. 5. Temperature (left) and salinity (right) sections along Line A. Units of temperature and salinity are ℃ and psu, respectively.

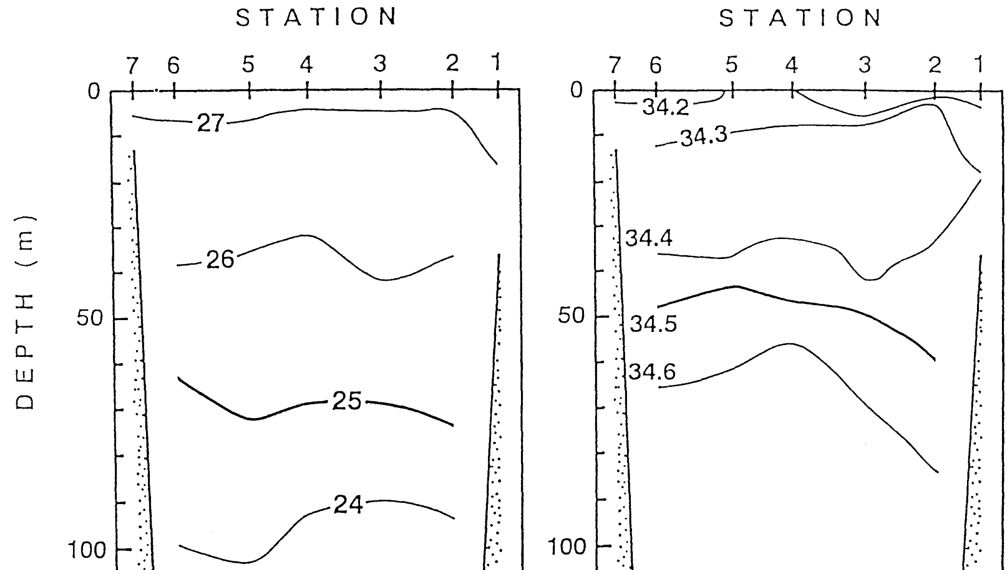


Fig. 6. Same as Fig. 5 except Line B.

The maximum depth of the ASTD measurements at every station was 200 m except Stn. C1. A strong vertical temperature gradient such as shown in Fig. 3, exists between 80 m and 190 m depths. A remarkable horizontal variation of temperature, a temperature contour rising, is found at Stn. C1 near the bay head. Temperature are horizontally variable in the thermocline, suggesting existence of small scale phenomena.

The salinity variations are mostly limited above 100 m depth unlike temperature (Fig. 8).

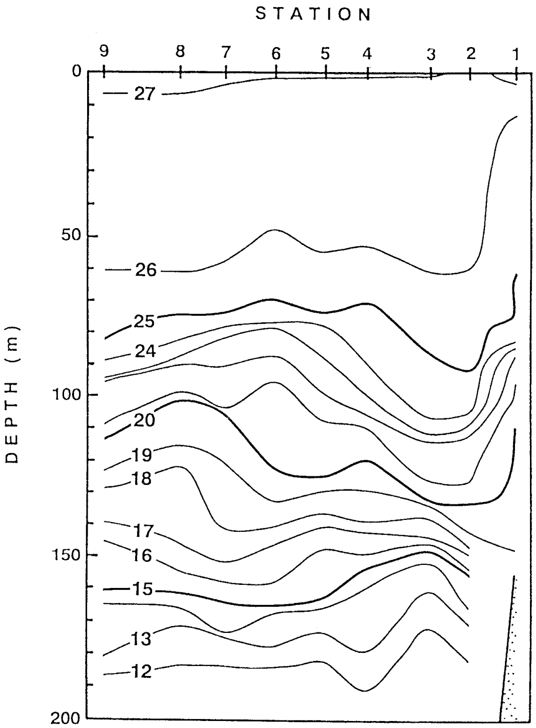


Fig. 7. Temperature section along Line C. Unit is ℃.

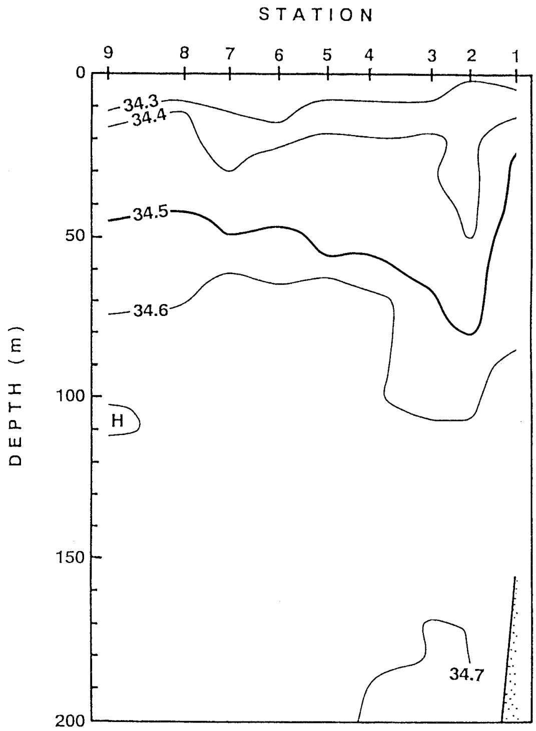


Fig. 8. Same as Fig. 7 except salinity. Unit is psu.

Then, there exists a continuously vertical density stratification due to salinity gradient in the surface layer (above 80 m depth) and to temperature variation in the thermocline. Also isohalines rise near the bay head, as isotherms. From only one station data, we cannot explain whether or not this cold, saline surface water near the bay head is due to the upwelling.

## 4. Discussion

The detailed temperature and salinity observations in Pelabuhanratu Bay indicated two interesting features; (1) difference of the vertical structure in between December 1994 and August 1995, (2) such horizontal variations of temperature and salinity as upwelling or small scall internal waves.

Figure 9a shows the temperature profiles observed at Stn. P in December 1994 and Stn. C4 in August 1995, nearly the same location at the center of the bay. Throughout the sea surface to 200 m, the temperature in August is lower than that in December. The temperature decrease of 2 ℃ in the surface layer and the

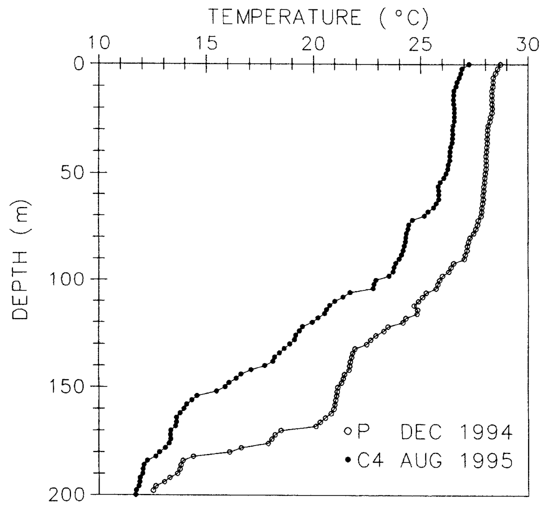


Fig. 9a. Temperature profiles.

thermocline rise of 40 m show the large heat loss during the period from December to August. Figure 9b shows that the salinity in August is higher above 80 m and lower below this depth than that in December. The vertical salinity variation in December is much larger

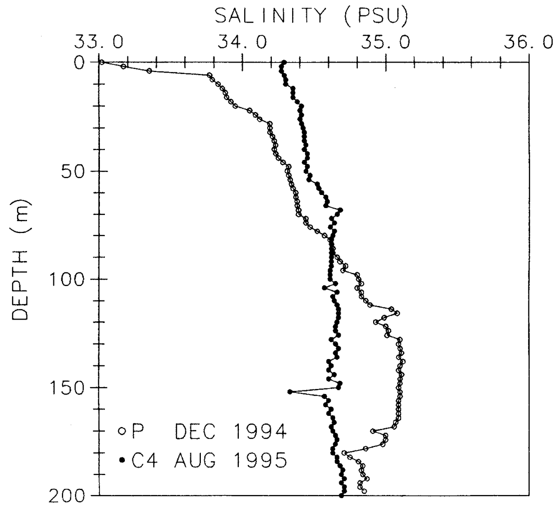

Fig. 9b. Same as Fig. 9a except salinity.

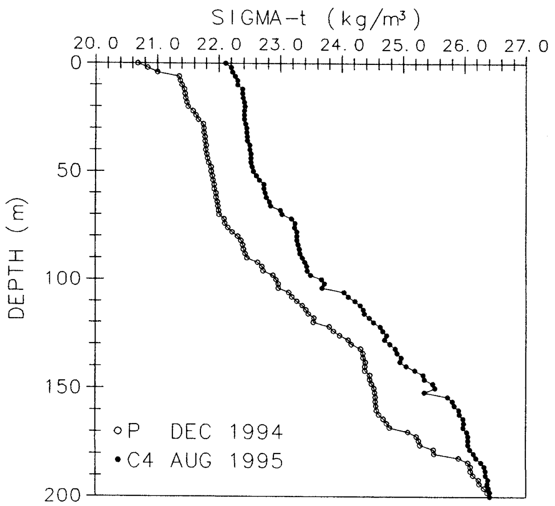

Fig. 9c. Same as Fig. 9a except sigma-t.

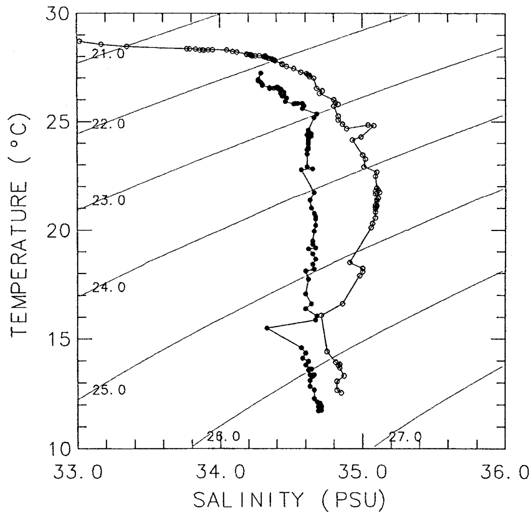

Fig. 10. T-S diagram at Stns. P (○) and C4 (●).

than that in August. The density in December is lower than that in August, but near 200m depth the difference disappears (Fig. 9c). The density difference between December and August is about 0.7 kg/m$^3$ from 10m to 180m. Figure 10 shows that the two T-S diagram of Stns. P and C4 do not agree with each other. The difference between both records may be considered by the seasonal variation which exists, at least, in the range from the sea surface to 200m depth.

We confirm whether or not the seasonal variation of the subsurface temperature exists in the southern coast of Java. JEXAM (Japanese Experiment on Asian Monsoon) reported the monthly-mean maps of 100 m depth temperature and 20 ℃ isotherm depth in the Indian Ocean (JEXAM, 1994). Figure 11 shows the temperature distributions at 100 m depth in December and August. The temperature at 100m at the west Java coast is 20 to 21℃ in August and 23 to 24℃ in December. The temperature difference between August and December in Pelabuhanratu Bay (Fig. 9a) agree with the monthly-mean temperature at the southern coast of Java (Fig. 11). Recently BRAY *et al.* (1996) analysed the XBT data from the Tropical Ocean-Global Atmosphere (TOGA) for study on the variation of the Indonesian throughflow. They showed the thermocline depth variation of about 10 m and the shollowest during July to September at annual period at the south coast of central Java. These studies indicate the existence of seasonal variation in the subsurface temperature along the south coast of Java. The seasonal variations of temperature and salinity are mainly induced through the sea surface by the air-sea heat and water exchange. In addition, the seasonal variations of wind (Asian monsoon: Fig. 12) can be considered to affect the vertical distributions of temperature and salinity in surface and subsurface layers, especially coastal region. We suppose the temperature decrease in the

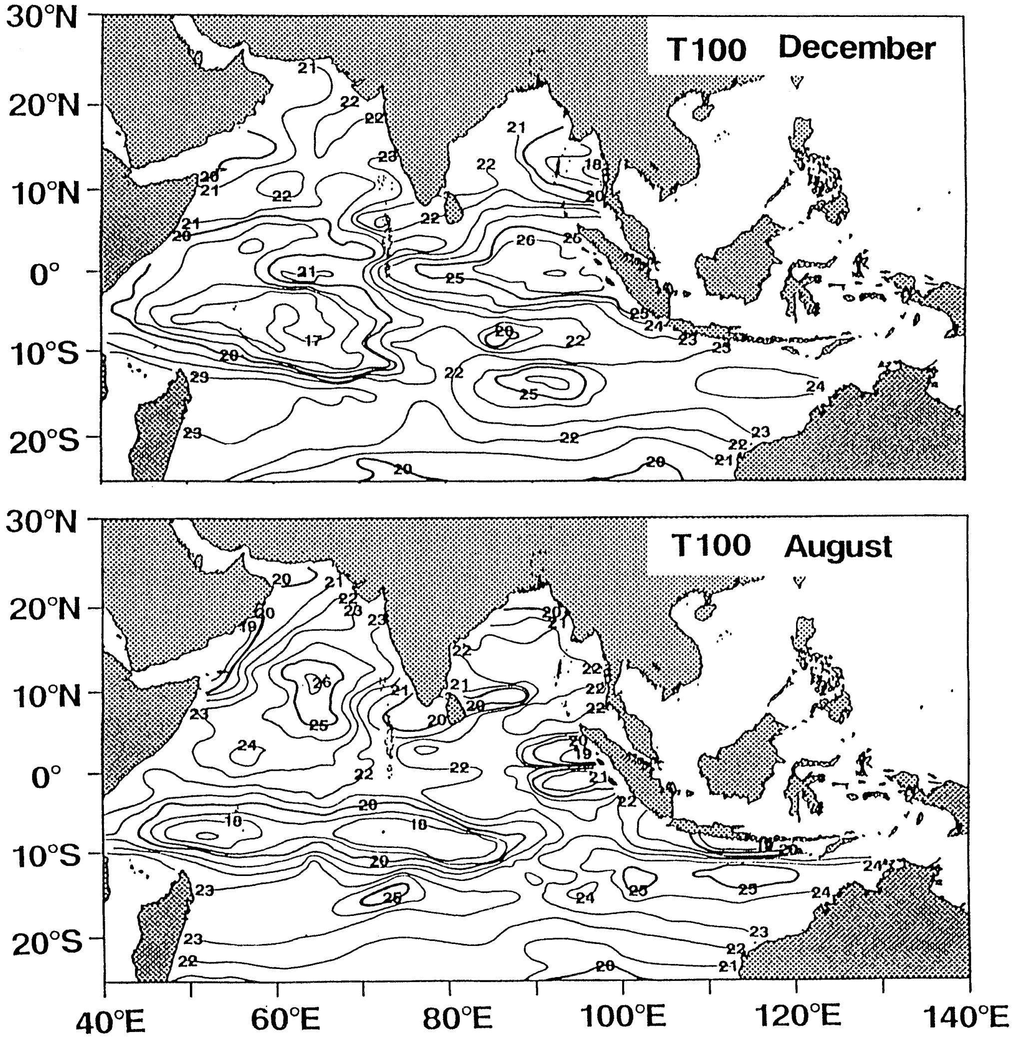


Fig. 11. Monthly-mean temperature at 100m depth in the Indian Ocean (after JEXAM, 1994). Unit is ℃.

surface layer from December to August to be induced by the air–sea heat exchange, and the thermocline rising to be related to the coastal upwelling by southwest monsoon in August (e.g. HELLERMAN and ROSENSTEIN, 1983; MIYAMA *et al.*, 1996).

Then, we consider the relation between the thermocline rising in August and the coastal upwelling in this region, i.e., the tropical region in the southern hemisphere. The width of the coastal upwelling is estimated as the internal radius of deformation (YOSHIDA, 1955; GILL, 1982), $a=c/f$, where c is the phase velocity of the first baroclinic mode and f the Corioris' parameter ($f=2\omega \sin \phi$ ; $\omega$ is the angular velocity of the earth and $\phi$ the latitude). Applying a typical value of c to be 2.8 m/s, as a typical value in the tropical region (WUNSCH and GILL, 1976) and $f=1.77\times10^{-5}s^{-1}$, the width of upwelling is estimated as about 158 km. This scale is much larger than the length of Pelabuhanratu Bay (about 20km), so it suggests that the thermocline rising occurs all the bay by the coastal upwelling in August, but the horizontal variations of thermocline depth in the bay due to the coastal upwelling can be less detected for the horizontally small difference.

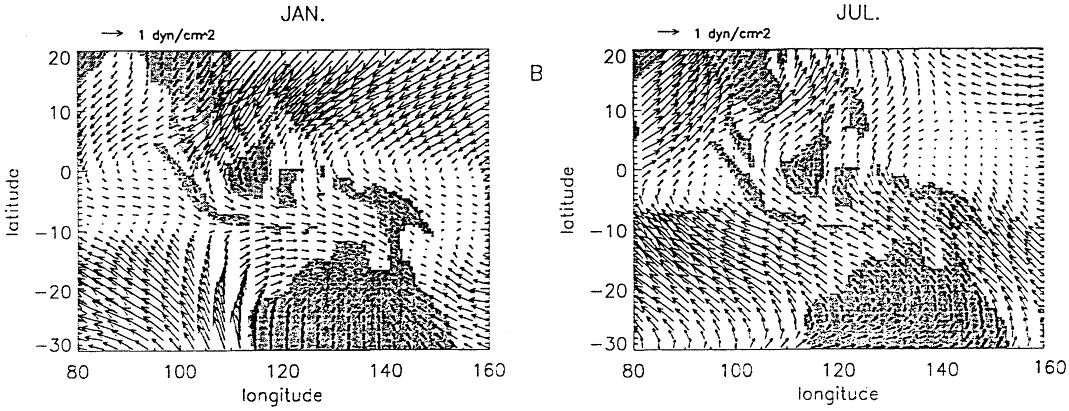


Fig. 12. Wind stress from January and July calculated by HELLERMAN and ROSENSTEIN (1983) (after MIYAMA *et al.*, 1996).

## 5. Summary

In December 1994 and August 1995, the field observations by STD carried out from the sea surface to 200m depth in Pelabuhanratu Bay, which is a small bay located at the southern coast of west Java, facing to the Indian Ocean. Remarkable diferences in temperature and salinity profiles between both months were seasonal variations. Compared with August, the high temperature and low salinity water occupied near the sea surface in December. In subsurface layer, the temperature in December are 2 to 5 ℃ higher than that in August through the water column of 200m, but the salinity in December is lower from the surface to about 80m depth than that in August but higher below the depth. The density stratification is affected by the salinity near the sea surface, but under 80m depth by the temperature. In the observations in August, the spatial variations of the thermocline existed along the bay axis, but it cannot be confirmed whether or not the upwelling occurred.

We would like to continue the observation for clarifying the seasonal change of the temperature and salinity fields in Pelabuhanratu Bay and its physical process, especially relating to the monsoon. In addition, the signal of ENSO can be frequently detected even in this region, so that the regular observation at every interval (e.g., every month) is possible to catch a important signal of the global climate-ocean change.

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