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Seasonal variation in sea surface temperature around Java derived from NOAA AVHRR

Suhendar I SACHOEMAR* and Tetsuo YANAGI**

Abstract : An observation of Sea Surface Temperature (SST) by using NOAA AVHRR data was conducted in the Java Sea and the Indian Ocean around Java in order to understand the seasonal variation and its spatial distribution during the period of 1995–1997. SST characteristic in the Java Sea was found to be significantly different from that in the Indian Ocean. Semi annual variation is dominant in the Java Sea, while in the Indian Ocean, annual variation is more dominant. Mean SST in the Java Sea is higher by 1–2℃ than that in the Indian Ocean, while SST maximum and minimum is higher by 1–4 ℃. SST in the Java Sea is mainly affected by net heat flux through the sea surface, while that in the Indian Ocean is influenced by the upwelling related to monsoon.

Key words : *SST, NOAA AHVRR, around Java*

1. Introduction

The Java Sea and the Indian Ocean around Java is the most important area for the economical activities in the western Indonesia. Both areas are characterized by different situation in terms of the economical activities and the environmental condition. The Java Sea existing between Java and Kalimantan is a shallow water. In this area, the activities are various from heavy industry, off-shore gas drilling, agriculture, coastal fishing to the transportation as a consequence of the urban concentrations in the northern coast of Java and southern coast of Kalimantan. While the Indian Ocean is an open sea and deep water. The main activity in this area is coastal and open sea fishing due to high productivity generated by the upwelling.

To understand the oceanographic and the environmental condition within these regions, some expeditions and investigations have been conducted by using expensive conventional methods with research vessels to derive a numerous oceanic parameters including sea surface temperature (SST). In the Java Sea, some expeditions to obtain a series of physical, chemical and biological data at some areas along the northern coast of Java have been conducted to reveal a basic knowledge of the environmental condition (LIPI, 1980 and 1981). While in the Indian Ocean, some observations have also been carried out to understand the upwelling processes (WYRTKI, 1962; RACHFORD, 1962; PURBA, 1995; SOERIATMADJA, 1957; PARIWONO *et al*, 1988) and water productivity from chlorophyll *a* concentration (NONTJI, 1977 and SETIAPERMANA *et al*, 1992). However, the knowledge of the temporal and spatial distributions of SST were still limited. SST is well known as a key parameter for detecting current, front, eddies and upwelling. Since SST data are needed for integrated study of the marine environment within these regions, a reasonable cost to retrieve a regular and continuous data should be selected. Satellite remote sensing data from NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer) can now offer an effective aid to solve such demand. Hence, the utilization of a synoptic time series SST data derived from NOAA AVHRR in our study is expected to complete the lack of information on the marine

* Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka
** Research Institute for Applied Mechanics (RIAM), Kyushu University, Fukuoka

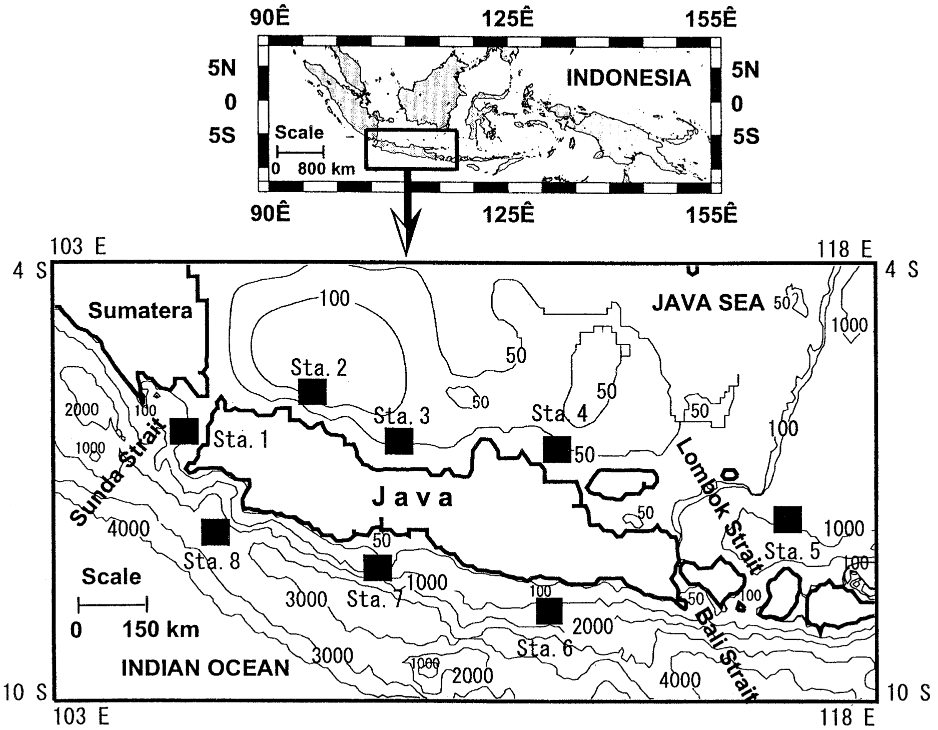

Fig. 1. Study area, bathymetry (meter) and SST sampling point in the Java Sea and the Indian Ocean.

environment condition within these regions. In this study, SST variation of the Java Sea and the Indian Ocean around Java will be described by analyzing the monthly mean SST variability. The upwelling phenomenon in relation with marine fish production will also be discussed.

2. Study area

Study area between 103–113°E and 4–10°S covers the Java Sea in the northern part and the Indian Ocean in the southern part. While in the western part and eastern part, the area is bounded by Sunda Strait and Bali Strait, respectively. These straits connect the Java Sea to the Indian Ocean and vice versa. Bathymetry of the Java Sea is less than 200 m and that of the Indian Ocean is more than 1000 m (Fig. 1).

3. Data collection and analysis

A time series of mean monthly SST of NOAA AVHRR satellite data derived from 1995–1997 in Version 4.1 with resolution of 9 km were obtained from NOAA Pathfinder to study SST variation in the Java Sea and the Indian Ocean. The AVHRR data are obtained by using a non-linear Sea Surface Temperature (NLSST) algorithm of Version 4.1. The data were validated and calibrated by match up of the AVHRR data and the in-situ observation data derived from TOGA (Tropical Ocean Global Atmosphere) and TAO (Tropical Atmosphere Ocean) buoys and it provides a high accuracy data with a negative bias of 0.1–0.2℃ (VAZQUEZ *et al.*, 1998). HELLERMAN and ROSENSTEIN (1983) monthly wind stress data with resolution of 2°×2°, bathymetry data of the National Geophysical Data Center (NGDC) with resolution of 5′×5′ were also collected to support this study. To understand the characteristic of SST variation in the Java Sea and the Indian Ocean, the mean monthly SST during 1995–1997 were mapped. To obtain a specific information of SST variation, SST at some points in northern and southern coasts of Java were also sampled from the mean monthly SST of each year. SST data of the Java Sea and the Indian Ocean were then analyzed by Fourier analysis to obtain an average, amplitude and phase of SST variation during 1995–1997. The equation of Fourier analysis is described on the below:

$$T_t = A_o + A_1 \sin wt + B_1 \cos wt + A_2 \sin 2wt + B_2 \cos 2wt \quad \cdots\cdots\cdots(1)$$

Where:

T_t : SST at time t

A_o: Average SST

w : Angular frequency with the period of 1 year

A_1 and B_1 : Constants for annual variation

A_2 and B_2 : Constants for semi annual variation

The amplitude and phase of the annual and semi annual variations were then obtained by the equations :

Amplitude of annual variation (Ap1) :

$$(A_1^2+B_1^2)^{1/2} \quad \cdots\cdots\cdots(2)$$

Phase of annual variation (Ph1) :

$$\tan^{-1}(B_1/A_1) \quad \cdots\cdots\cdots(3)$$

Semi annual amplitude (Ap2) :

$$(A_2^2+B_2^2)^{1/2} \quad \cdots\cdots\cdots(4)$$

Semi annual phase (Ph2) :

$$\tan^{-1}(B_2/A_2) \quad \cdots\cdots\cdots(5)$$

To support this study, sea surface heat flux was also calculated on the basis meteorological data at Jakarta, oceanographic data at Jakarta Bay and equations of KIM and KIMURA (1995), EFIMOVA (1961) and KONDO (1975). While to understand correlation of the upwelling existence on the marine productivity within these regions, a series of fish production data at some places in northern and southern coasts of Java as well as their SST variability were also analyzed.

4. Results

Temporal and spatial variations of the monthly mean SST in the period of 1995–1997 around Java are shown in Fig. 2. During the northwest monsoon from January to March, SST in the Java Sea and the Indian Ocean show almost the similar range, that is within 28–29 ℃. Entering to the transition period of April to May, SST in the eastern part of the Indian Ocean begins to decrease from 28 to 27℃. During the southeast monsoon from June to September, SST gradually decreases and reaches to the lowest level less than 25℃ in the Indian Ocean in August and September, and low SST spatially propagates to the western part. In the southeast monsoon, SST in the Indian Ocean is lower by 1–4℃ than that in the Java Sea. On the other hand, SST in the Java Sea during the transition period of April to May slightly increases from 28–29℃ to 29–30℃ and decreases to 27–28℃ during the southeast monsoon. In the transition period of October to November, SST in the eastern part of the Java Sea gradually increases to 28–30℃ and SST in the eastern part of the Indian Ocean to 27–28℃. During the transition periods of April to May and October to November, SST in the Indian Ocean is lower by 1–2℃ than that in the Java Sea.

Temporal variations of SST at representative stations are shown in Fig. 3. Stas. 2–4 represent the SST variability in the Java Sea and Stas. 6–8 in the Indian Ocean. SST variation in the Java Sea shows the different character from that in the Indian Ocean. Semi annual variation is dominant in the Java Sea, while annual variation is dominant in the Indian Ocean. SST in the Java Sea is slightly fluctuated within the range of 27–30℃ with semi annual oscillation during 1995–1997. While in the Indian Ocean, SST variability is larger and fluctuated within 24–30℃ with annual oscillation in 1995, 26–30 ℃ in 1996 and 23–29℃ in 1997. Moreover, SST maximum in the Java Sea ranged 29–30℃ and occurred twice a year in April and November. While SST minimum in the Java Sea ranged 27–28 ℃ and occurred in January and August. In the Indian Ocean, SST maximum ranged 28–29℃ and occurred once a year in April. While SST minimum in the Indian Ocean ranged 23–27℃ and occurred in September.

The average SST from 1995–1997, the amplitude and phase of annual and semi annual SST variations in the Java Sea and the Indian Ocean, which were obtained by Fourier analysis, are shown in Fig. 4. The results show that the average SST in the Java Sea is higher by 1–2℃ than that in the Indian Ocean. The amplitude of SST in the Java Sea shows the semi annual variation with range of 0.5 to 1.0℃. This

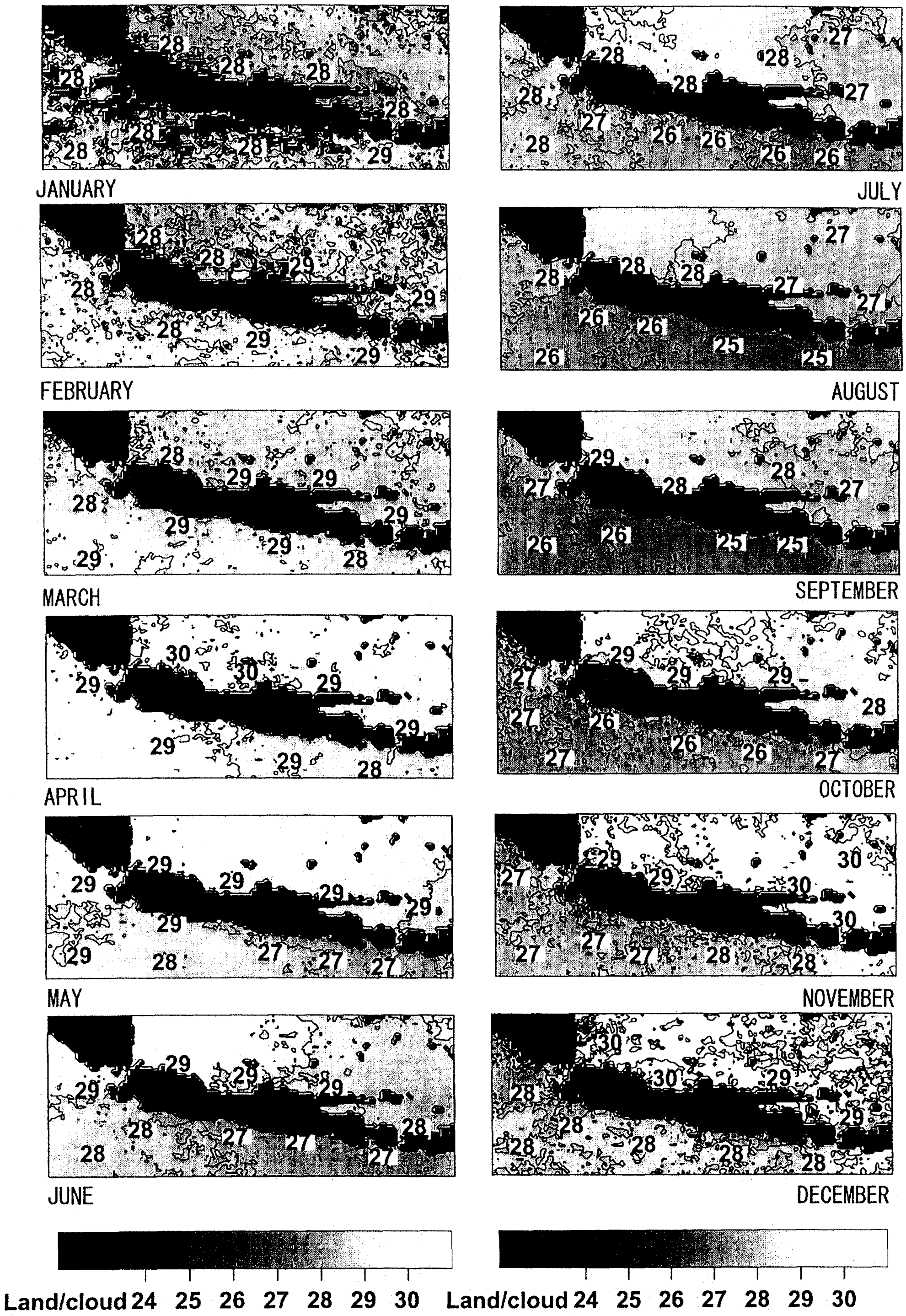

Fig. 2. Average monthly SST (°C) variation during 1995–1997.

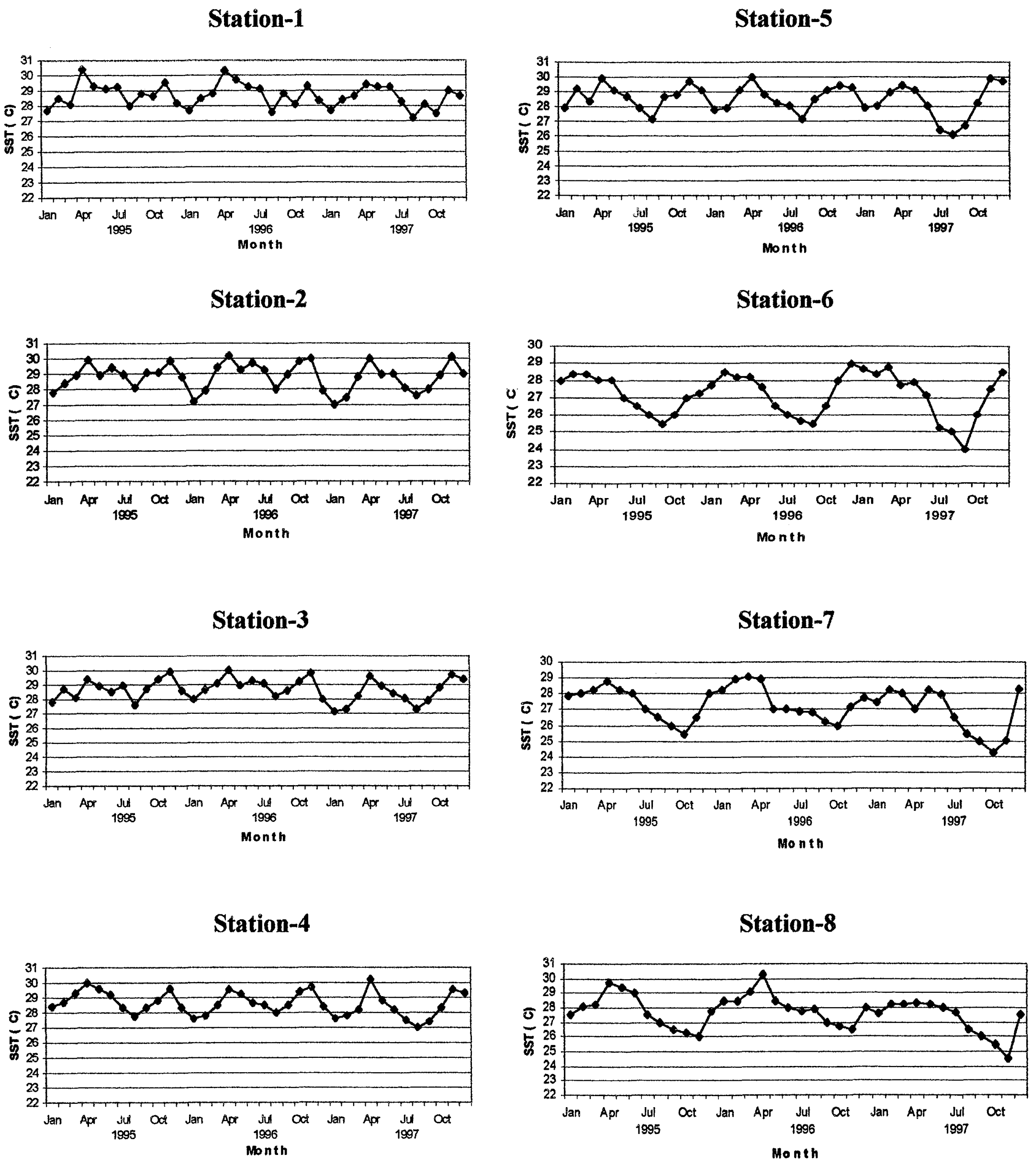

Fig. 3. Monthly mean SST variations during 1995–1997 at some sampling points in the Java Sea and the Indian Ocean.

value is smaller than that of the annual variation of SST in the Indian Ocean with range of 1.0 to 1.5℃.

Temporal and spatial variations of wind stress are shown in Fig. 5. During the northwest monsoon from January to March, the northwesterly wind over the Java Sea is weak. Entering to the transition period of April to May, the southeasterly wind gradually increases and reaches to the strongest level in August and September. During such period, the northwesterly wind is disappeared. The southeasterly wind is then weakened entering to the transition period of October to

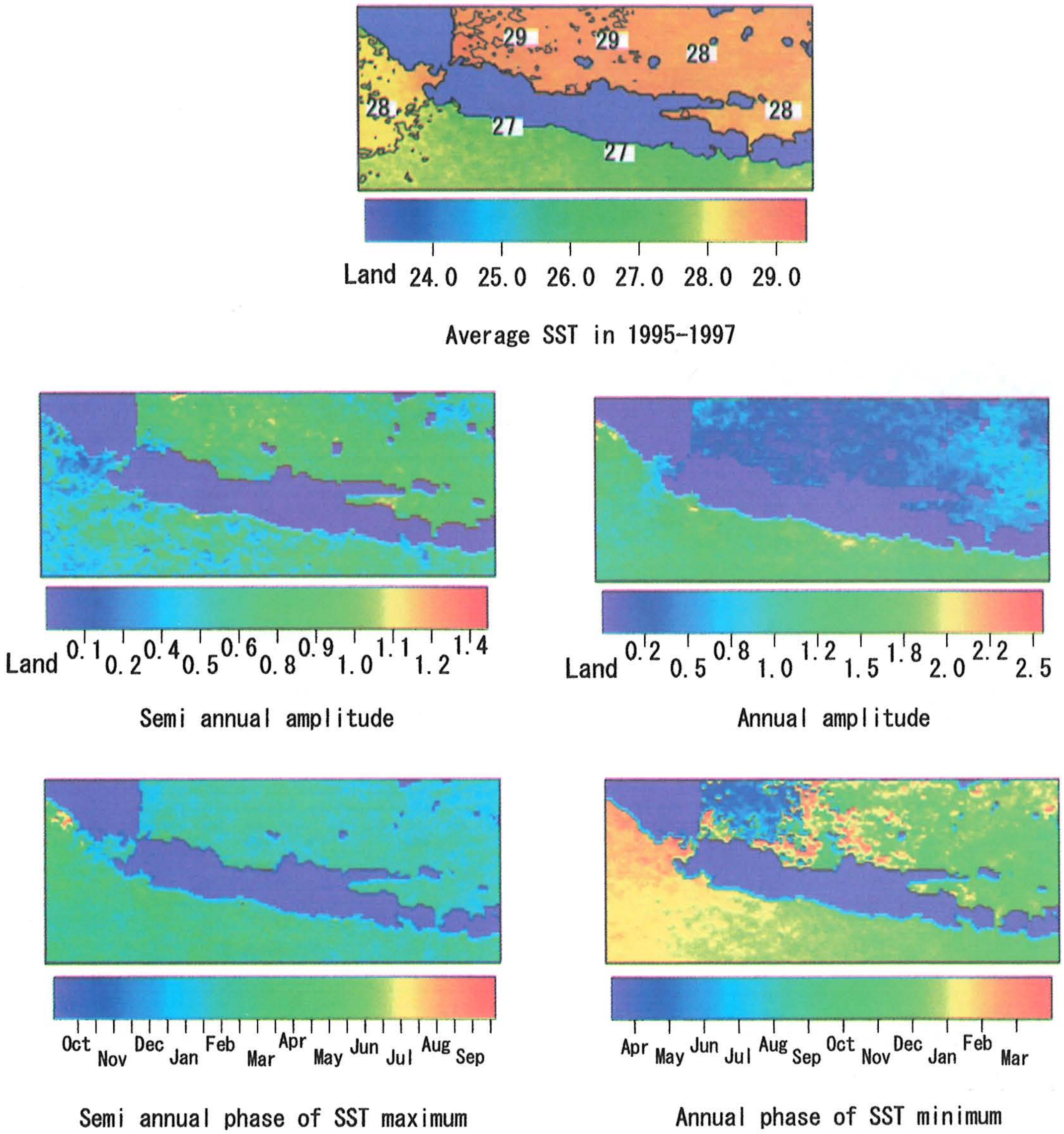

Fig. 4. Average SST, amplitude and phase of semi annual and annual variations in the Java Sea and the Indian Ocean.

November.

5. Discussion

Bathymetries of the Java Sea and the Indian Ocean are significantly different and such condition reflects on the difference of SST characteristics between these areas. The Java Sea is shallow water where the depth is less than 200 m, while the Indian Ocean is a deep water where the depth is more than 1000 m. This situation obviously affects on the characteristic of SST variation.

Mean monthly SST in the Java Sea is relatively higher by 1–2℃ than that in the Indian Ocean. It is due to the effect of subsurface cold water in the Indian Ocean. SST variability in the Java Sea may be mainly governed by the net heat flux (Qnet) variability which shows a

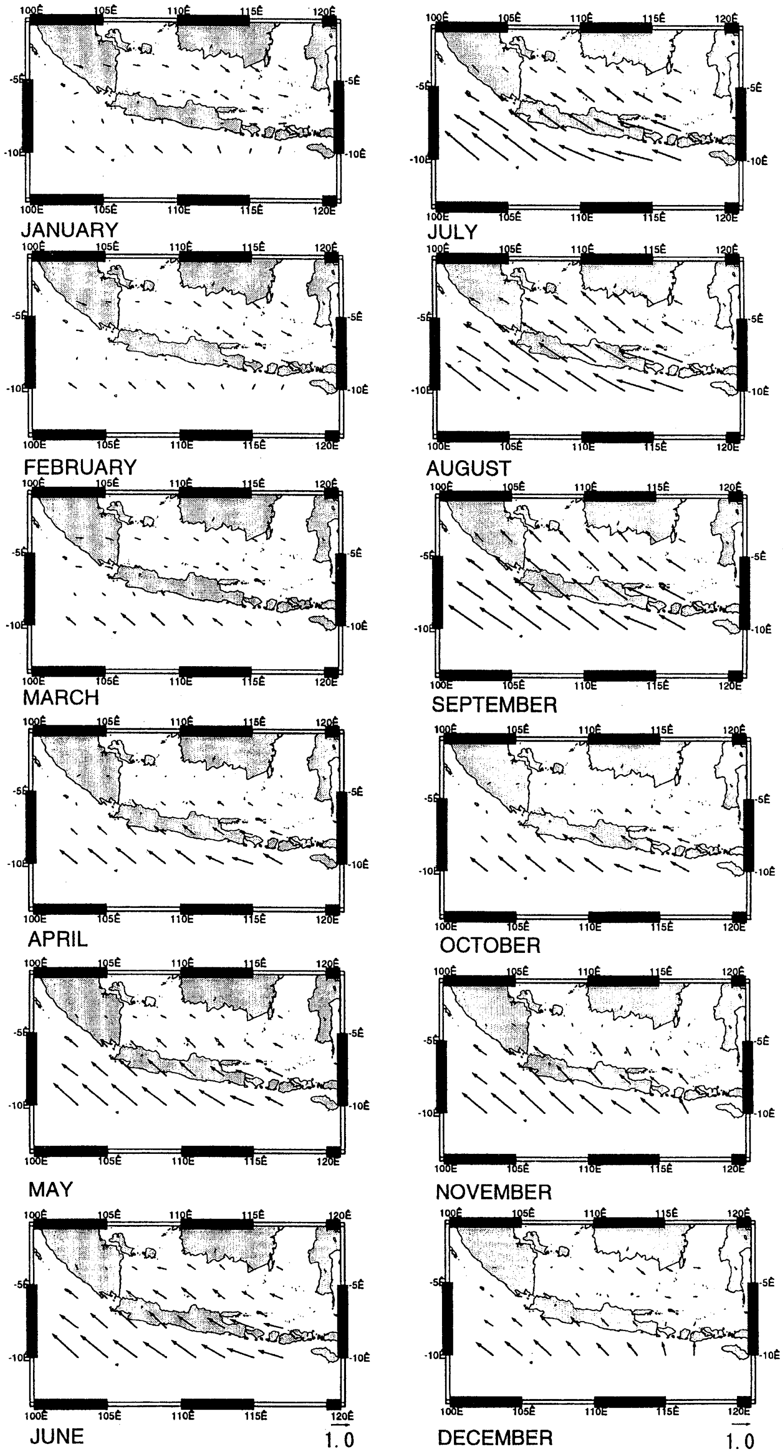

Fig. 5. Monthly mean wind direction and stress (dyne/cm^2) over the Java Sea and the Indian Ocean.

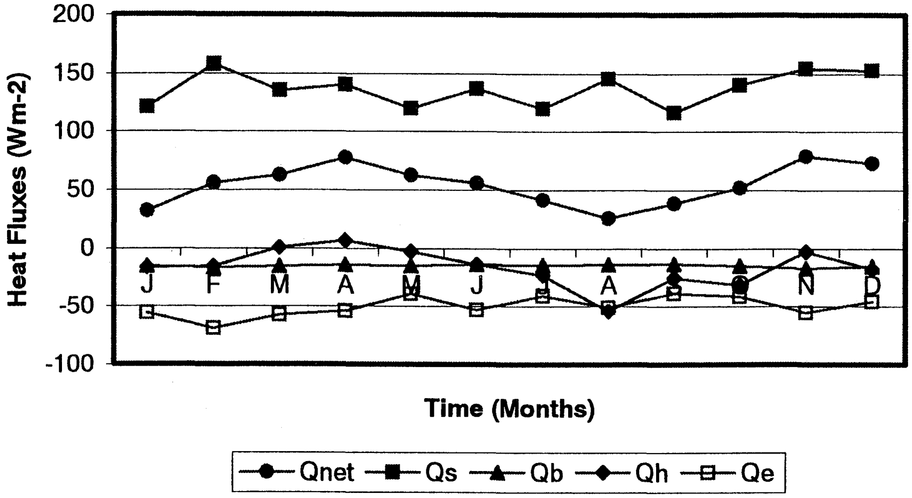

Fig. 6. Mean annual heat flux (Wm^{-2}) around the Java on the basis of the data from Meteorological Agency, Indonesia, during period of 1931–1960. Q_{net}, Q_s, Q_b, Q_h and Q_e are net heat flux, short-wave, long-wave, sensible and latent heat fluxes, respectively.

semi annual variation as shown in Fig. 6. While in the Indian Ocean, SST variability mainly influenced by the monsoon where annual variation becomes more dominant. SST maximum in the Java Sea occurs in the transition period of April and November when the sun crosses the equator and the net heat flux (Qnet) is large. While SST minimum in the Java Sea occurred in January due to the small net heat through the sea surface. Also in August, SST minimum occurred due to another small net heat flux. On the other hand, SST minimum in the Indian Ocean occurred in September in the eastern part due the strongest upwelling that is generated by the sea surface Ekman transport as response to the strongest southeasterly wind. This situation has been occurred from June with the westward propagation of low SST minimum and reaches to the peak of the upwelling with minimum SST in September. This situation was confirmed by the result of spatial distribution of the lower SST in time function during the upwelling period of the southeast monsoon and the effect of the southeasterly wind speed on the SST at the same period as shown in Fig. 7.

Previous study (WYRTKI, 1962 and PURBA, 1995) described that the upwelling in the southern coast of Java, the Indian Ocean, was developed during the southeast monsoon (July–September). But our results shown in Fig. 2, denotes that the upwelling begins in May and ends in November. Figure 2 and 3 also show that the occurrence of upwelling within this region is different between the eastern part and the western part. In the eastern part, the upwelling developed earlier than that in the western part as well as for the ending. This situation is supported by the wind stress shown in Fig. 5, that is, the southeasterly wind begins to develop in April and still exists in November in the western part. Though the upwelling has already ended in the eastern part in November, the upwelling process is still occurred in the western part. It is obviously seen on the SST status in November where SST in the eastern part was higher than that in the western part following the weakening of the southeasterly wind entering to the transition period, while in the western part, the southeasterly wind was still strong. Nevertheless, more detail investigation through the comprehensive field observation should be conducted to confirm that situation. Our result also noticed that the strongest upwelling was occurred in September in the eastern part. It is shown by the appearance of the coldest water along the coast spreading offshore up to 100

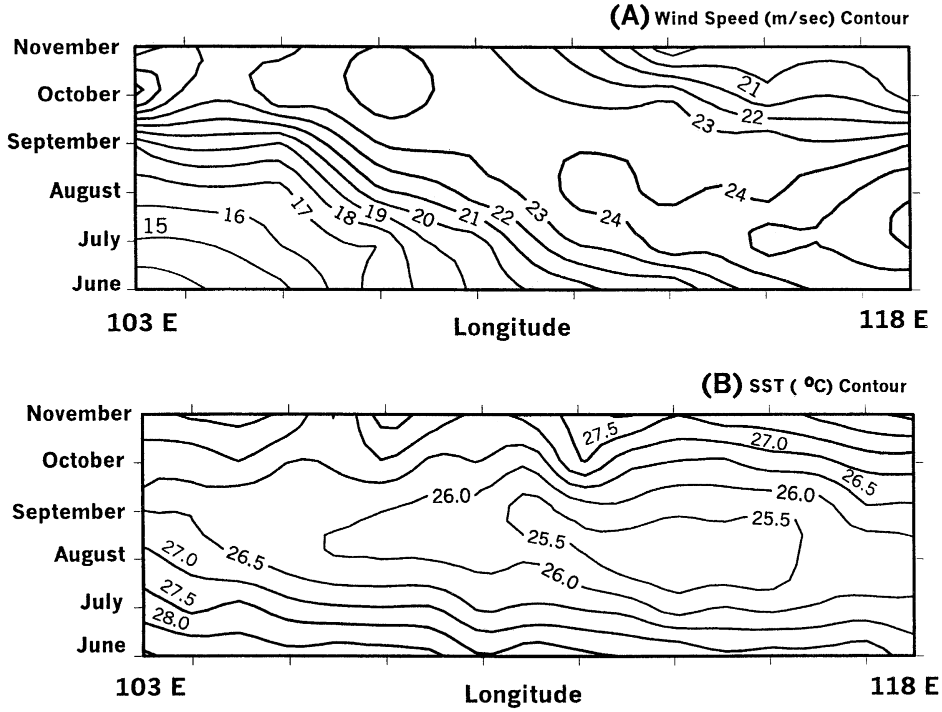

Fig. 7. Wind speed (A) and SST (B) distributions along the southern coast of Java, Indian Ocean during the upwelling period of June–November.

km as shown in Fig. 2.

The existence of the upwelling along the southern coast of Java has provided a good impact on fish production as shown in Fig. 8. Fish production in the Southern Coast of Java during the period of 1995–1997 was significantly higher than that in the Java Sea. Moreover fish production during the upwelling season from June to November was greater and regularly reach more than 900 ton month^{-1} through the year. This situation indicated that the upwelling area in the southern coast of Java is more productive than that in the Java Sea where the upwelling was not occurred. The fish catch mostly composes of skipjack, blue fin tuna and yellow fin tuna, an oceanic and seasonal migratory fish that has strong correlation to the seasonal upwelling in the southern coast of Java.

6. Summary and Conclusion

SST variabilities in the Java Sea and the Indian Ocean show the different characters, that is, semi annual variation is dominant in the Java Sea, while an annual variation is dominant in the Indian Ocean. Average, maximum and minimum SST in the Java Sea is higher by 1–2℃ than those in the Indian Ocean due to the effect of the upwelling. In general, SST variability around Java is controlled by bathymetry, net heat flux (Qnet) and monsoon. SST in the Java Sea is mainly controlled by the net heat flux, while that in the Indian Ocean is strongly influenced by the monsoon. SST in the Java Sea slightly changes throughout the year but in the Indian Ocean, SST dramatically changes through the seasons. The existence of the prevailing southeasterly wind during the southeast monsoon is a main factor causing the upwelling phenomenon in the southern coast of Java and it promotes fishing activity due to the increasing of marine productivity. To reveal more detailed upwelling processes in relation to the marine productivity within this region, the utilization of ocean color images is strongly recommended for the future study.

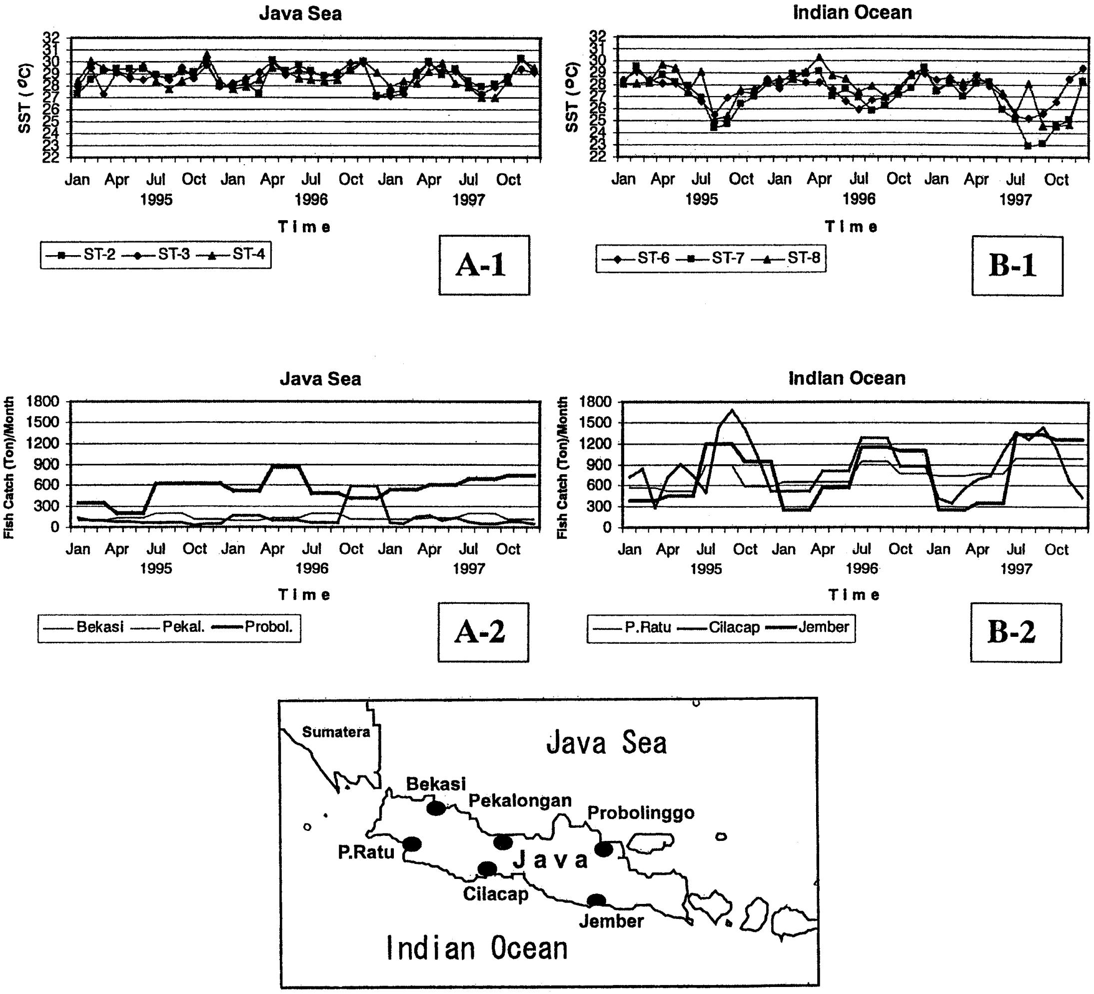

Fig. 8. Year to year variations of SST (A-1) and fish production (A-2) in the Java Sea; year to year variations of SST (B-1) and fish production (B-2) in the Indian Ocean obtained from some places in the northern coast of Java (Java Sea) and southern coast of Java (Indian Ocean) from 1995-1997.

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