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Literature review of the climatology of the Java Sea

Ibnu Sofian* and K. Kozai*

Abstract

Indonesian througflow is the gateway of inter-ocean transport between the North Pacific and the Indian Ocean. The Java Sea is the major route of the western path of Indonesian througflow. The climatology of the Java Sea and the Makassar Strait surface currents is reviewed. As far as the El Niño and La Niña are concerned, the sea level variations and the surface transport of the Java Sea and the Makassar Strait are very important. This paper also presents the interconnection between the Java Sea and the Makassar Strait surface current, particularly during the El Niño and La Niña.

Keywords: Java Sea, Makassar Strait, Indonesian throughflow, El Niño, La Niña

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1. Introduction

The Indonesian Seas consist of very deep basins in the east and the shallow Java Sea in the western part. The Java Sea is a shallow body of sea and has average depths of around 40 to 50 meters. It connects to the Sulawesi Sea to the northeast by the Makassar Strait, adjoins the Flores Sea to the east, connects to the South China Sea to the northeast via Karimata Strait, and Kalimantan to the north (Tomszack and Godfrey, 2001).

Fig.1 displays the bathymetry of Indonesian Seas. The largest and the deepest is the Banda Sea that has depths in excess of 4500 m in the southeast (also known as the South Banda Sea) and in the northwest (the North Banda Sea), separated by a ridge of less than 3000 m depth; largest depths are near 7440 m in the south and 5800 m in the north. The Sulawesi Sea (formerly known as the Celebes Sea) is a single basin of similar size deeper than 5000 m over most of its area. Between these two major basins are three basins deeper than 3000 m, the Molucca, Halmahera, and Seram Seas, the latter being deeper than 5300 m. The Flores Sea is located in the south, connecting the Banda Sea with the shallow Java Sea and reaching nearly 6400 m in a deep depression. Another important topographic feature is the Makassar Strait between the Sulawesi and Java Seas. The Makassar Strait is shallow in the west but over 2000 m deep in the east where it is connected without obstruction to the Sulawesi Sea in the north (Tomczak and Godfrey, 2001).

The climate of the Indonesian Sea is characterized by monsoonal winds and high rainfall. Fig.2 shows the wind vector patterns within the Indonesian Seas during January and August for 7 years mean (1993 to 1999). The wind vector data are calculated based on ERS (European Remote Sensing) satellite wind field (CERSAT and IFREMER, 2001). Winds blow from the south, curving across the equator with a westward component in the south and an eastward component in the north, during May to September and in nearly exactly the opposite direction during November to March (Tomczak and Godfrey, 2001). During the southeast monsoon from May to September, the easterly and southerly wind blow in the Java Sea and the Makassar Strait, respectively. Furthermore, during the northwest monsoon from November to March, the Java Sea and Makassar Strait wind directions are changed from easterly and southerly to westerly and northerly, respectively. Fig. 3 shows the three climate regions according to the mean annual precipitation patterns using the double correlation method (DCM). Region A (solid line) covers south and central Indonesia from south Sumatera to Timor Island, parts of Kalimantan, parts of Sulawesi, and parts of the Papua Islands. Region B (short dashed line) is located in northwest Indonesia and covers the northern part of Sumatera and the northwestern part of Kalimantan Islands. Region C covers Maluku and parts of Sulawesi (close to the western Pacific region) (Aldrian and Susanto, 2003).

The mean annual rainfall cycles of each region and their interannual standard deviations are described in Fig. 4. Region A has one peak and one trough and experiences strong influences of two monsoons, namely the wet northwest (NW) monsoon from November to March and the dry southeast (SE) monsoon from May to September. Region B has two peaks, in October–November (ON) and in March to May. Those two peaks are associated with the southward and northward movement of the Inter-Tropical Convergence Zone (ITCZ). Region C has one peak in June to July (JJ) and one trough (November–February). The JJ peak in Region C is about 300 mm/month, whereas the peaks in Regions A and B are 320 mm/month and 310 mm/month respectively. The minimum in

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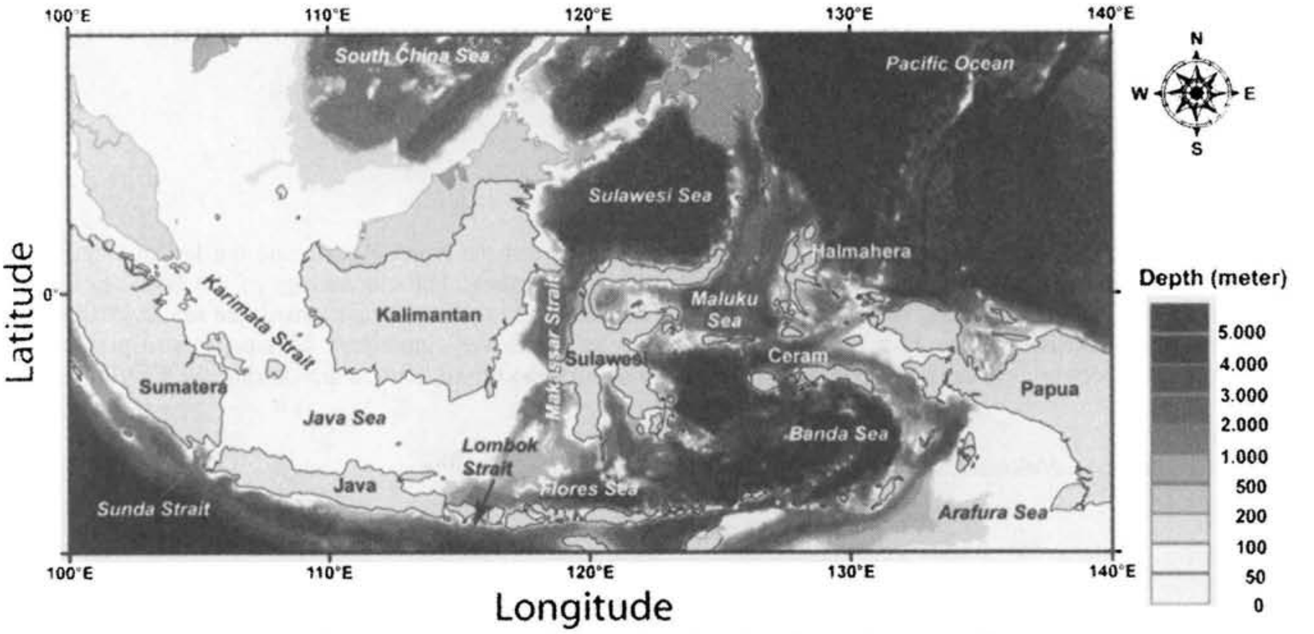
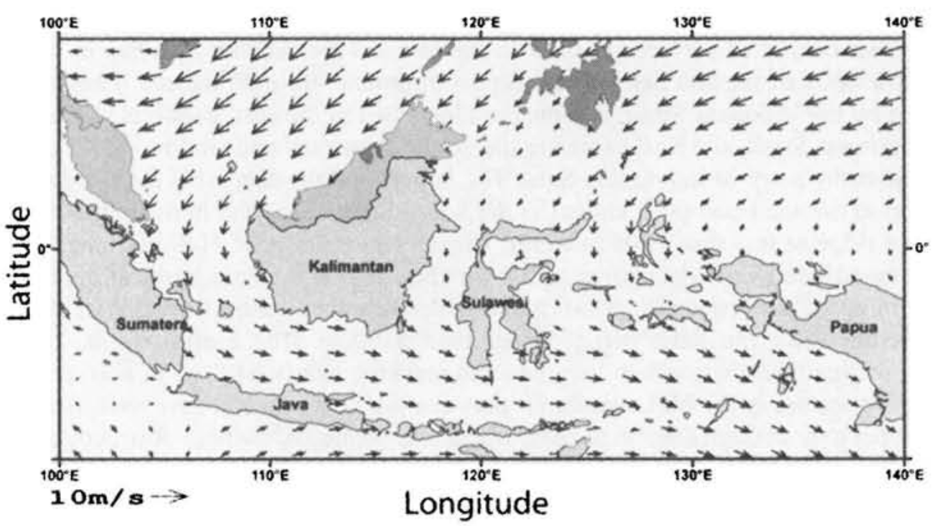
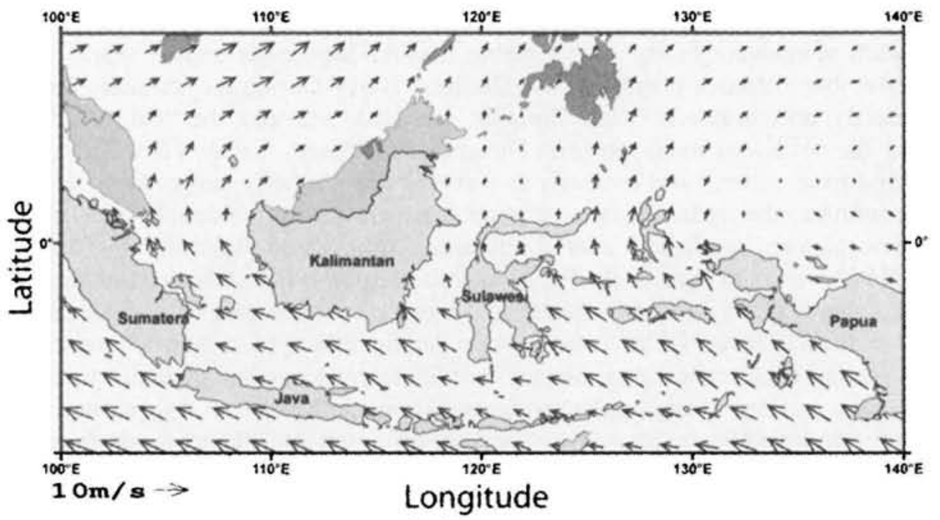


Fig. 1. Bathymetry of the Indonesian Seas (based on Etopo2)



a. January



b. August

Fig. 2. Wind vector patterns within the Indonesian Seas during January and August for 7 years mean (1993 to 1999). The wind vectors are based on the ERS (European Remote Sensing) satellite.

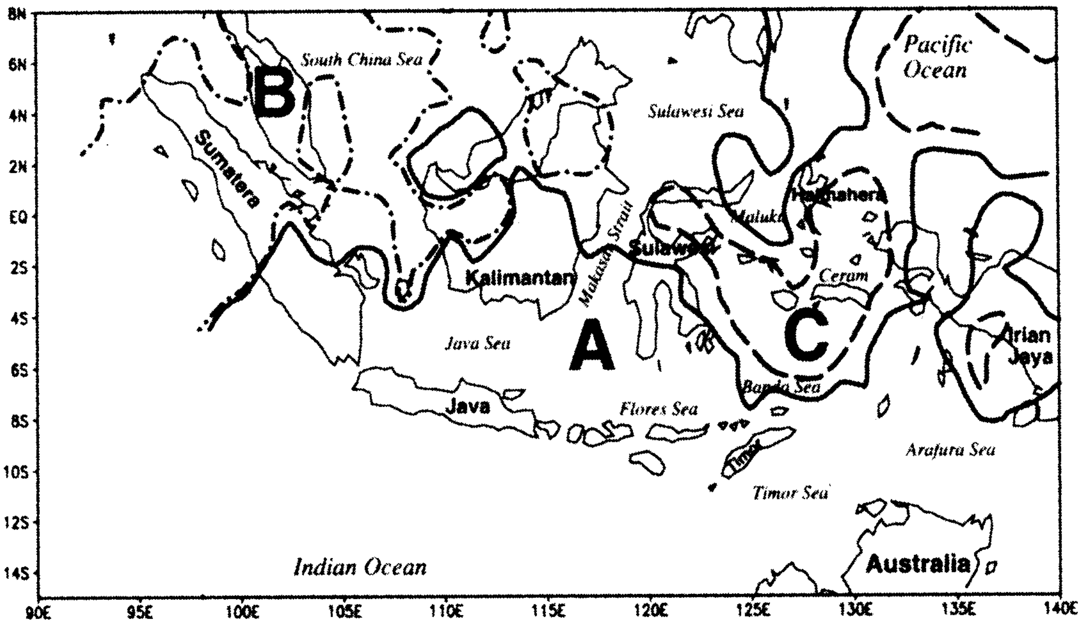


Fig. 3. The three climate regions according to the mean annual precipitation patterns using the DCM. Indonesia is divided into Region A in solid line, Region B in short dashed line and Region C in long dashed line. (Aldrian and Susanto, 2003)

Region A is the lowest and reaches a mean below 100 mm/month. Thus, Region A is the driest region during the dry season in July–September and the wettest region in December (Aldrian and Susanto, 2003).

2. Sea level variations and Indonesian througflow during the ENSO years

El Niño Southern Oscillation (ENSO) is the most prominent interannual climate variability in the world climate. It is well known that ENSO is associated with devastating droughts over the western tropical Pacific, torrential floods around the eastern tropical Pacific, and unusual weather pattern over the world (Nkendirim, 2000). A large scale weakening of the trade winds and warming of the surface layers in the eastern and central equatorial Pacific Ocean characterizes El Niño. El Niño events occur irregularly at intervals of 2 to 7 years, although the average is about once every 3 to 4 years (McPhaden, 1993). And during the strong 1997 to 1998 ENSO years particularly during the northwest monsoon, Indonesia had severe drought (Kumar et al., 1999).

Centre of the ENSO problem is the evolution of near-equatorial sea surface temperature (SST) (Harrison, 1990). In the western Pacific warm pool is migrated eastward with the collapse of the trade winds (McPhaden, 1999). Based on the higher correlation between SST and sea level and between SOI and sea level Nerem and Mitchum (2001) developed simulated long-term series of global mean sea level variations. A large increase in global mean SST was observed since 1982, and the largest changing occurred during the ENSO event from 1997 to 1998, SST was changed about 0.35°C (Nerem, 1999, Nerem and Mitchum, 2001).

The characteristic of Indonesian throughflow was affected by ENSO. Ffield et al. (2000) found the high correlation between the thermocline temperature (average temperature between 150m to 400m) and the southward Makassar transport. Ffield et al. (2000) also found that SOI has highly correlated with thermocline temperature. From these relationships during the El Niño period the total of the southward Makassar Strait transport is low and high during the La Niña period. However, the surface of the southward Makasar Strait southward transport (0m to 200m) is high during the El Niño and low during the La Niña (Sofian et al., 2006). Using the physical model, Waworuntu et al. (2000) explained that the strengthening of the pressure gradient in the lower thermocline between the Pacific Ocean and the Indonesian Seas during the La Niña period could increase the flow in the deeper thermocline from the Banda Sea to Makassar Strait. Gordon and Susanto (2002) reported sea level anomalies of Banda Sea were high during La Niña and drop to the lowest in the El Niño period. The same phenomena were also recorded in the Java Sea during the El Niño period. Sea level was dropped to the lowest during the El Niño period and the highest was occurred in the La Niña period (Sofian and Kozai, 2003). In the eastern Indian Ocean, the significant interannual variability of the upwelling along the southern coast of the Java

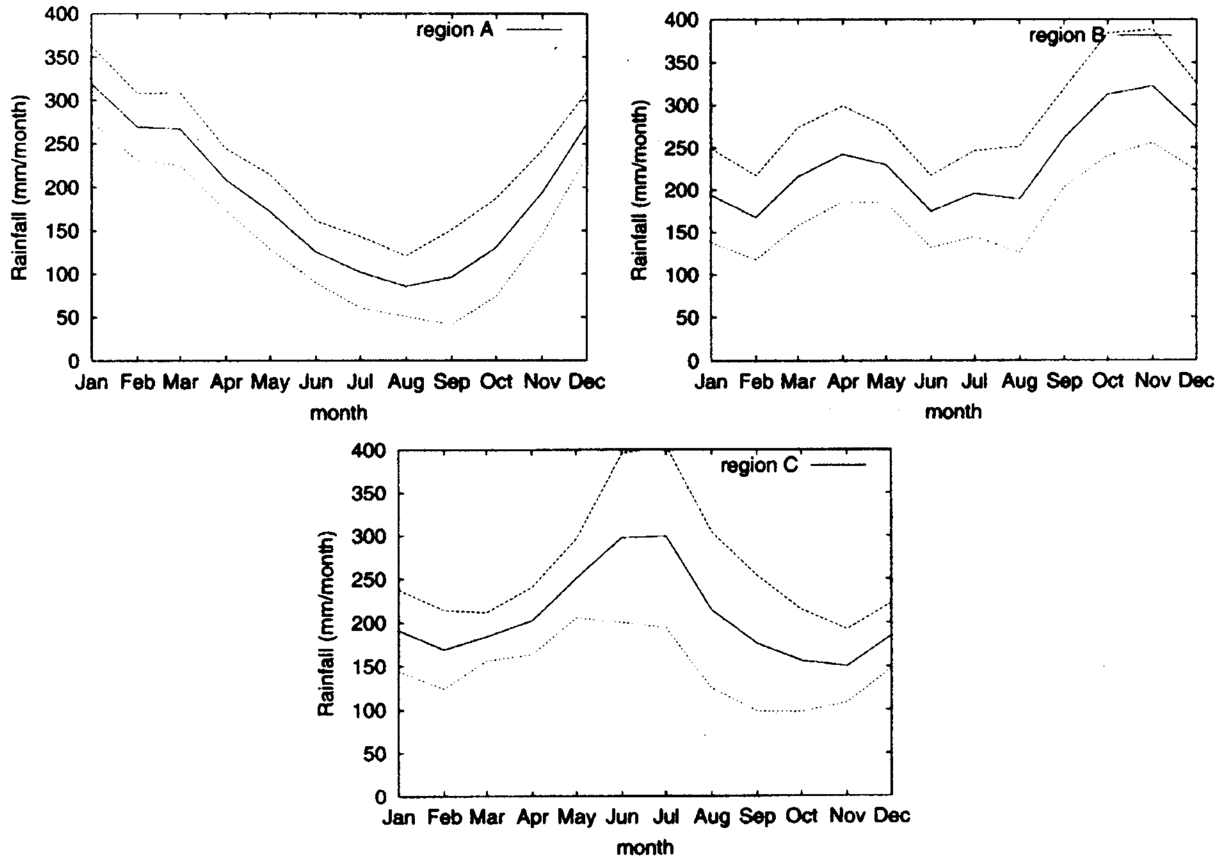


Fig 4. The annual cycles of the three climate regions (solid lines) using the DCM. Dashed lines indicates one standard deviation (σ) above and below average (Aldrian and Susanto, 2003)

and Sumatera islands is linked to the ENSO by way of the Indonesian troughflow and by anomalous easterly wind (Susanto et al., 2001).

Past observations show that the water composing of the Indonesian throughflow is derived from the North Pacific thermocline, though at greater depth it is directly drawn from the Indian Ocean (Gordon and Fine, 1996). During the northwest monsoon from January to March, the Java Sea low-salinity surface water shifts into the southern Makassar Strait. During the southeast monsoon, from July to September, the southern Makassar Strait surface layer is more saline and less buoyant, as the southeast monsoon winds return the low-salinity water into the Java Sea. The buoyant surface water of the southern Makassar Strait inhibits southward transport within the surface layer during the northwest monsoon, despite southward wind within the Strait, lowering the temperature of the Indonesian throughflow (Gordon et al., 2003). The low surface salinities of the Java Sea are due to heavy precipitation and large river runoff from the Java and Kalimantan Islands. During the northwest monsoon, the eastward zonal wind expels the low salinity, buoyant water of the shallow Java Sea into the surface layer of the southern Makassar Strait. During the southeast monsoon, more saline water of the Flores and Banda Sea conveys into the Java Sea, shifting the buoyant surface water from the southern Makassar Strait into the western Java Sea and the South China Sea.

The Java Sea transport is eastward 2 Sverdrup (Sv, 1 Sv= 1million m^3/sec) during the northwest monsoon, and westward 1 Sv during the southeast monsoon (Sofian et al., 2006). The eastward Java Sea transport is getting larger during the La Niña period and inhibits the southward Makassar Strait surface transport. The strong eastward Java Sea transport also generates the small northward Makassar Strait surface transport during this period. Conversely, the southward Makassar Strait surface transport is larger during the El Niño period. The large southward Makassar Strait transport reduces the Java Sea eastward transport during this period (Sofian et al., 2006).

Southward transport within the Makassar Strait shows high correlation with the thermocline temperature (averaged between 150 m and 400 m). During high (low) temperature, the volume transport is also high (low) (Ffield et al., 2000). Gordon et al. (2003) showed the result from the measurement using MAK-1 and MAK-2 moorings that the largest volume transport was occurred during the La Niña period, and getting smaller during the El Niño period. The direct measurements from MAK-1 and MAK-2 moorings were 12.5 Sv during the La Niña months of December 1996 through February 1997, and 5.1 Sv during El Niño months of December 1997 through February 1998 (Gordon et al., 1999).

Bray et al. (1996) calculated correlation between wind stress and sea level in the Indonesian Througflow. The correlation between sea level and wind stress was small. Also Bray et al. (1996) found that correlation between SOI and sea level anomaly was high in the eastern part of Indonesian Seas and small in the western part. Gordon et al. (1999) measured the current and throughflow within the Makassar Strait by deploying two moorings in the Makassar Strait. They found that the 1997 average througflow within Makassar Strait was 9.3 Sv. Also they assumed that the throughflow within the Makassar Strait can account for all from the Pacific to the Indian interocean transport. Although this measurement period was short, they found that correlation between the water transport and ENSO was high about 0.73.

3. Interconnection between the Makassar Strait and connected sea in term of surface current

Susanto et al. (2000 and 2001) investigated intraseasonal variability and tides along the Makassar Strait using spectral and time-frequency analysis. Semidiurnal and diurnal tides are dominant features, with higher semidiurnal and lower diurnal in the north compared with the south. Also they found that intraseasonal variability probably is a response to remotely Kelvin waves from Indian Ocean through Lombok Strait and to Rossby waves from the Sulawesi Sea.

Fig. 5 shows the Indonesian sea surface current during the northwest monsoon and the southeast monsoon respectively (Gordon 2006). The surface current within the Java Sea, the Makassar Strait and the Flores and Banda Seas are modulated by the monsoonal wind. However the current within the thermocline depth (from 150m to 400m) shows the southward directions from the West Pacific to the Indian Ocean. During the northwest monsoon, surface current from the Java Sea which has lower temperature and lower salinity shifts into the Makassar Strait, and the strong wind-induced eastward Java Sea surface currents reduce and inhibit the southward Makassar Strait surface flow. As the northwest monsoon comes to an end, the prevailing winds change direction and the process is reversed. From May to September, winds blowing to the north and west push the low salinity water back into the Java Sea. However the Makassar Strait surface southward flow is getting stronger and enters to the Java Sea during this period.

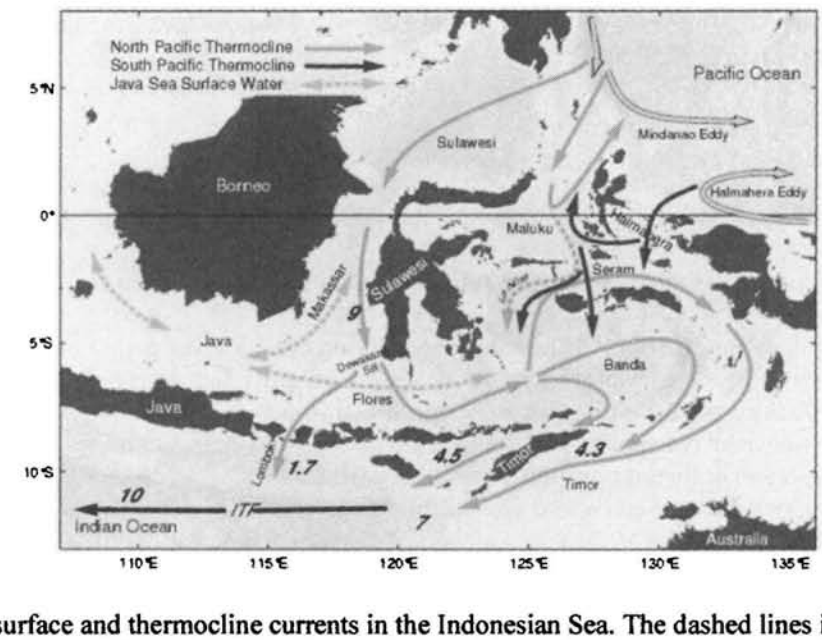
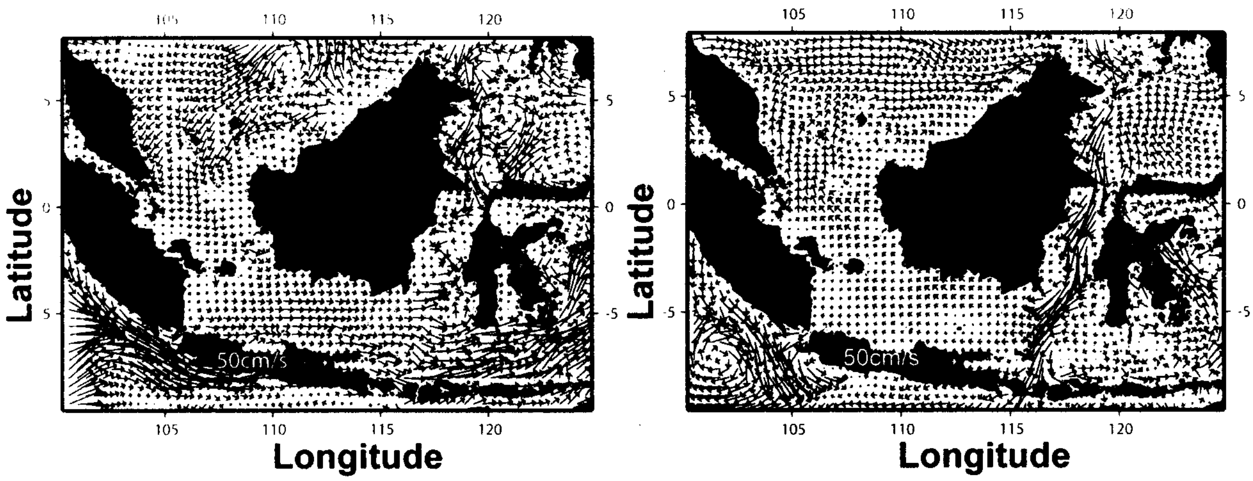


Fig. 5. Sketch of surface and thermocline currents in the Indonesian Sea. The dashed lines indicate the surface current, and the solid lines indicate the currents within the thermocline depth (Gordon, 2006).

Fig. 6 shows the surface current characteristics based on the ocean model results in January and August during the northwest and the southeast monsoons respectively (Sofian et al., 2006). The Java Sea surface flow is eastward and westward during January and August respectively. During the northwest monsoon, the monsoonal wind drives the Java Sea and the Karimata Strait surface water to eastward and southward respectively. The Sunda Strait surface current is directed to eastward and enters from the Indian Ocean to the Java Sea during this period. On the contrary, the wind direction is changed from northwesterly to southeasterly during the southeast



(a) January (b) August

Fig. 6. Surface current distributions based on the model results for the Java Sea region during (a) January and (b) August during 1993 to 1999 (Sofian et al., 2006).

monsoon. The wind-driven westward current expels the Java Sea and the Karimata Strait surface water westward and northward respectively. The Sunda Strait surface water exits from the Java Sea to the Indian Ocean during the southeast monsoon. On the other hand, the Makassar Strait current does not follow the monsoonal wind direction. The Makassar Strait surface currents tend to southtward. The southward Makassar Strait surface current speed is low during the northwest monsoon period, though the wind is northerly wind. The low southward Makassar Strait current speed is possibly caused by the strong Java Sea eastward current that inhibits the southward Makassar Strait current during the northwest monsoon. Furthermore, the southward Makassar Strait current speed is getting faster during the southeast monsoon. The strong southward Makassar Strait current push back the low salinity and low temperature of surface water back to the Java Sea (Gordon et al., 2003). The strong westward Java Sea current may cause the high sea level within the northern coast of the Java Island. The strong westward current creates the sea level gradient. The sea level is high in the western part of the Java Sea, and low in the southern part of the Makassar Strait (Sofian et al., 2006).

4. Summary

Based on the review of the climatology of the Java Sea, the summary of this paper can be described as follows.

1. The sea level of the Banda Sea and the Java Sea is high and low during the La Niña and the El Niño periods, respectively.
2. The eastward Java Sea transport is getting larger during the La Niña period and inhibits the southward Makassar Strait surface transport. The strong eastward Java Sea transport also generates the small northward Makassar Strait surface transport during this period. Conversely, the southward Makassar Strait surface transport is larger during the El Niño period. The large southward Makassar Strait transport reduces the Java Sea eastward transport during this period.
3. The strong westward Java Sea current creates the sea level gradient. The sea level is high in the western part of the Java Sea, and low in the southern part of the Makassar Strait.

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