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Water Mass Characteristics in the Strait of Malacca using Ocean Data View

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ABSTRACT
The main purpose of this project was to identify the pattern of water masses in Malacca Strait. The physical properties of seawater investigated were water temperature, salinity and dissolved oxygen over the Monsoon season. Ocean data view software was used to process the data and to create contour visualizations. Data from world ocean database were taken from 1900 to 2005. The results show the significant low salinity input from West coast Peninsular Malaysia in Northeast Monsoon season. During Southwest Monsoon period, there was an intrusion of high saline water from Andaman Sea to the Strait. The blowing of Southwesterly wind may push seawater from Indian Ocean and Andaman Sea intruding the Strait from the Northern sector. The Strait also were found to be more stratified in warmer condition. However, Southern sections are more homogeneous in every season indicating better mixing. This further study can improve the better understanding of seasonal water mass variation in the Strait of Malacca.

Key words: Northeast Monsoon, Southwest Monsoon, Strait of Malacca, water mass, water movement

INTRODUCTIONS
The Strait of Malacca is an international seaway. It links the Indian Ocean and Andaman Sea at the North to the South China Sea at the South. The wide section and the depth of the Northern Malacca Strait declines and narrows gradually to the Southern Strait. The Strait of Malacca has a tropical weather with the monsoon winds reversing directions twice a year. The two main monsoonal periods are the wet Northeast Monsoon and the warm and drier season Southwest Monsoon. They are strongly influenced the water movement and hydrographic parameters in the Strait (Wyrtki, 1961; Chua *et al.*, 2000). It is estimated that around 0.94×1011 m^3 of annual discharge from 14 rivers in Sumatra (Jaya *et al.*, 1998) and 9.35×10^{10} m^3 of annual discharge from 12 rivers from West coast of Peninsular Malaysia enter the Strait of Malacca (Chua *et al.*, 1997; Hii *et al.*, 2006).

From earlier studies, Pang and Tkalich (2003) identified that during the Northeast Monsoon, water from the South China Sea penetrates at least into the Southern part whereas, Tomczak and Godfrey (2003) and Ibrahim and Yanagi (2006) discussed the intrusion of the Andaman Sea from the Northern part of the strait during Southwest Monsoon. Ibrahim and Yanagi (2006) also claimed that the movements of these water masses are affect the physical properties of seawater, such as salinity, water temperature and dissolved oxygen.

The understanding of water mass variation over the monsoon seasons is essential to supervise management of this strait. A previous analysis of the seasonal variations (Ibrahim *et al.*, 2003) had indicated the importance of the Andaman Sea to the Malacca Strait circulation. The main purpose of this paper is to identify the seasonal pattern of water masses from investigation of the physico-chemical properties of seawater in the Strait of Malacca using Ocean data view software.

MATERIALS AND METHODS

Study location: The World Ocean Database 2005 (WOD 05) datasets at National Oceanic and Atmospheric Administration (Boyer *et al.*, 2006) Live Access Server (data available at http://www.nodc.noaa.gov/OC5/ WOD05/ data05geo.html) provided the source of the data used in this study. Water temperatures, salinity and dissolved oxygen were analyzed. The final dataset comprised 11508 stations from 1900 to 2007. This resulted in a total of 327594 samples of the Strait of Malacca waters. The monthly and yearly data distributions are shown in Fig. 1a and b.

The data processing and contour plot visualizations was created using Ocean data view software version 3.3.1 (Schlitzer, 2007) was used. The station data in the strait were categorized into two monsoon seasons (Table 1). Data are presented using surface contour and vertical contour plots of five cross-sections in the Strait of Malacca area.

Earlier study by Ibrahim and Yanagi (2006) observed only one vertical contour plot from North to South along the strait. This study provide further observation of vertical contour plot analysis by dividing the Strait into 5 sections labeled A, B, C, D and E at five different locations (Fig. 2). Sections of A and B were located at cross-sections with depths of more than 200 m in the Northern Strait, section C in the middle, while sections of D and E were located at depths of less than 60 m in the Southern Strait. This approach enables comparison to be made between the Eastern part and

Table 1: Monsoon periods used for sea data separation

Season	Period (months)
Northeast monsoon	November, December, January, February (NDJF)
Southwest monsoon	May, June, July, August (MJJA)

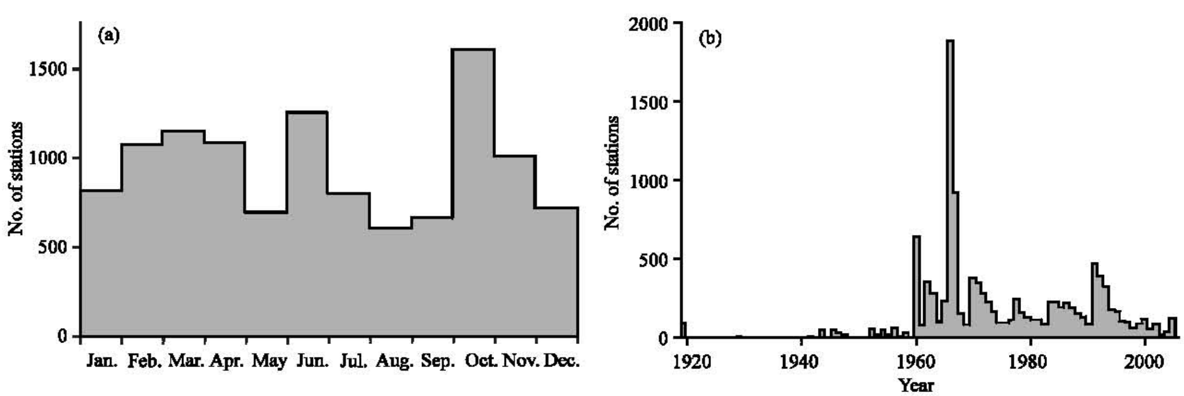

Fig. 1: Temporal Distribution of station data in Malacca Strait. (a) The number of stations data available by month and (b) the number of stations data available year by year

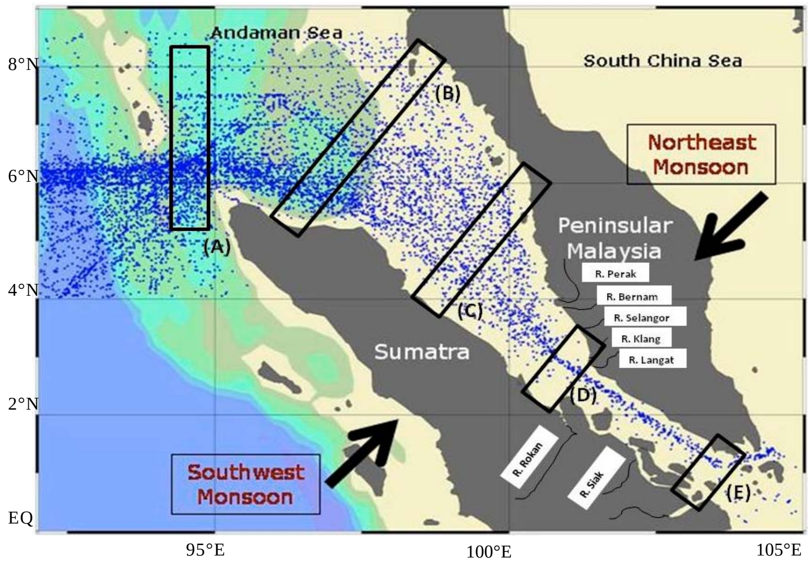

Fig. 2: Location of the Strait of Malacca study area and location of stations from the world ocean data base 2005. The four sections labeled A, B, C and D used for vertical section plots are also indicated

the Western part of the strait for different water depth while providing the better visualization of the strait stratification. The scale of the X and Y (distance and depth) axis for the vertical contour plot in the five sections are changed from section A to section E to account for the change in waterdepth. For the Northern sections, the Y scale is from 0 to 150 m and the middle section from 0 to 100 m. While in the Southern sections, the Y scale is from 0 to 60 m.

The World Ocean Database 2005 (WOD 05) dataset were processed for station data quality: stations located on land were removed; TS curves were checked for data consistency.

RESULTS AND DISCUSSION

Surface properties: Figure 3 shows the annual variations in surface water temperature, salinity and dissolved oxygen in the Strait of Malacca. The surface water temperature in Northeast Monsoon ranged between 28 and 29°C. This is increased to ~30°C during the Southwest Monsoon. The values of surface salinity in Northeast Monsoon were ~31 psu. Concurrently, there is an input of less saline water around 30.5 psu from west coast of Peninsular Malaysia. During Southwest Monsoon, the movement of high saline water from Andaman Sea (Fig. 3b) around 32 to 33 psu was observed intruding the Strait from the Northern sector. For dissolved oxygen, the values of 4.4 to 4.6 ml L^{-1} in Western part, especially in the middle and Northern Strait were higher than Eastern part, ~4.3 ml L^{-1} in Northeast Monsoon. However, the result during Southwest Monsoon indicates that the dissolved oxygen values were lower in Southern part of the Strait, around 4.1 ml L^{-1} than 4.4 to 4.6 ml L^{-1} at the Northern Strait.

Vertical properties

Temperature: Figure 4 shows the seasonal vertical variation in water temperature for the sections A-E in the Strait of Malacca. Comparison of the vertical sections for each season shows that lower values of water temperature occurred during the Northeast Monsoon (Fig. 4a) while the values increase in Southwest Monsoon (Fig. 4b). This is similar to the surface variation of temperature mentioned previously. At sections B of depths less than 50 m, the layer observed in Fig. 4b was ~28°C, was deeper than that shown in Fig. 4a. The temperature in Fig. 4b at sections C, D and E also show the higher values around 30°C at the upper layer, higher than the values in Fig. 4a.

Salinity: Figure 5 shows the seasonal vertical variation in water salinity for sections A-E in the Malacca Strait region. Observation of sections A-C show that the Strait were more saline during Southwest Monsoon. The high saline water valued around 35 psu was observed at the bottom of section A (Fig. 5b). The deep water from Andaman Sea was expected to intrude from the bottom of the Strait (Hii *et al*., 2006). At a depth of less than 40 m in section B, the salinity values was ~32.5 psu were observed in Fig. 5a as 5b indicated the values about ~33.5 psu. There was a significant intrusion of low saline water from West part in section C and D of Fig. 5a from 30 to 31.5 psu. It was assume that high precipitation in Northeast Monsoon lead to high river discharges from West coast Peninsular Malaysia to the strait. A study by Tan *et al*. (2006) indicated the effect

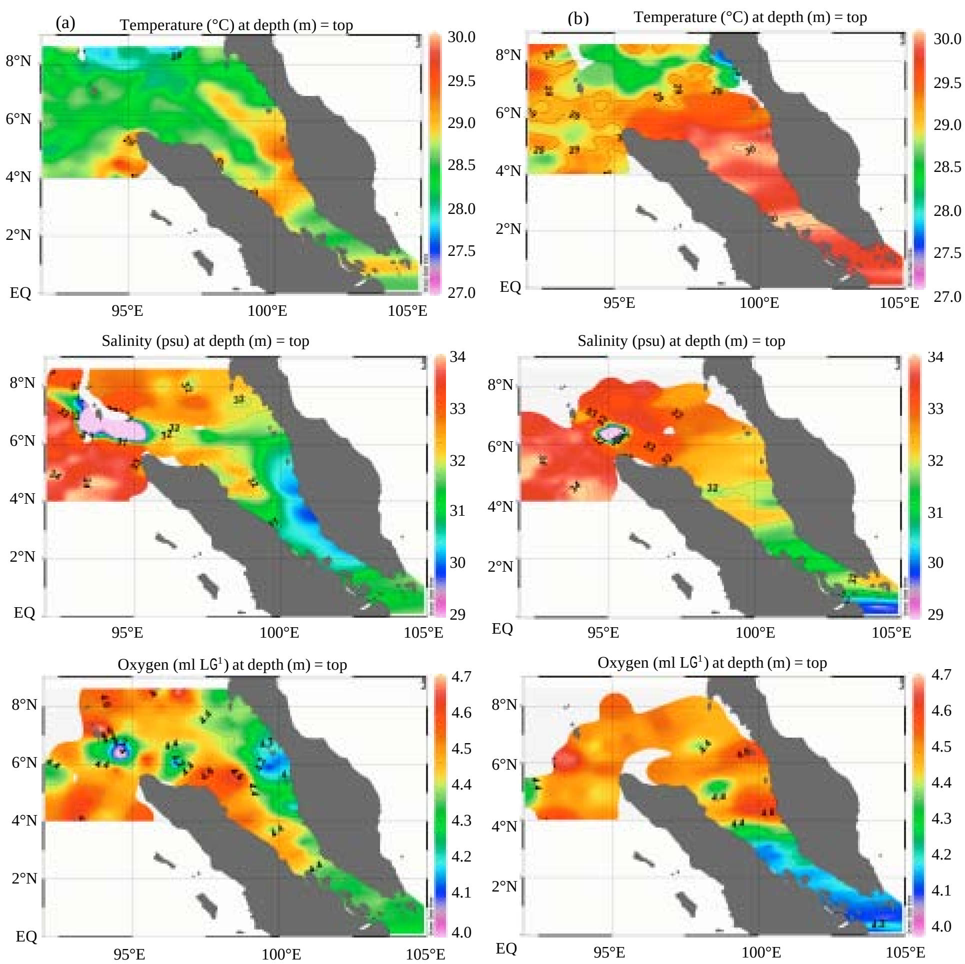

Fig. 3: Seasonal horizontal variations in surface water temperature and salinity in the Malacca Strait. (a) Northeast Monsoon season. (b) Southwest Monsoon season

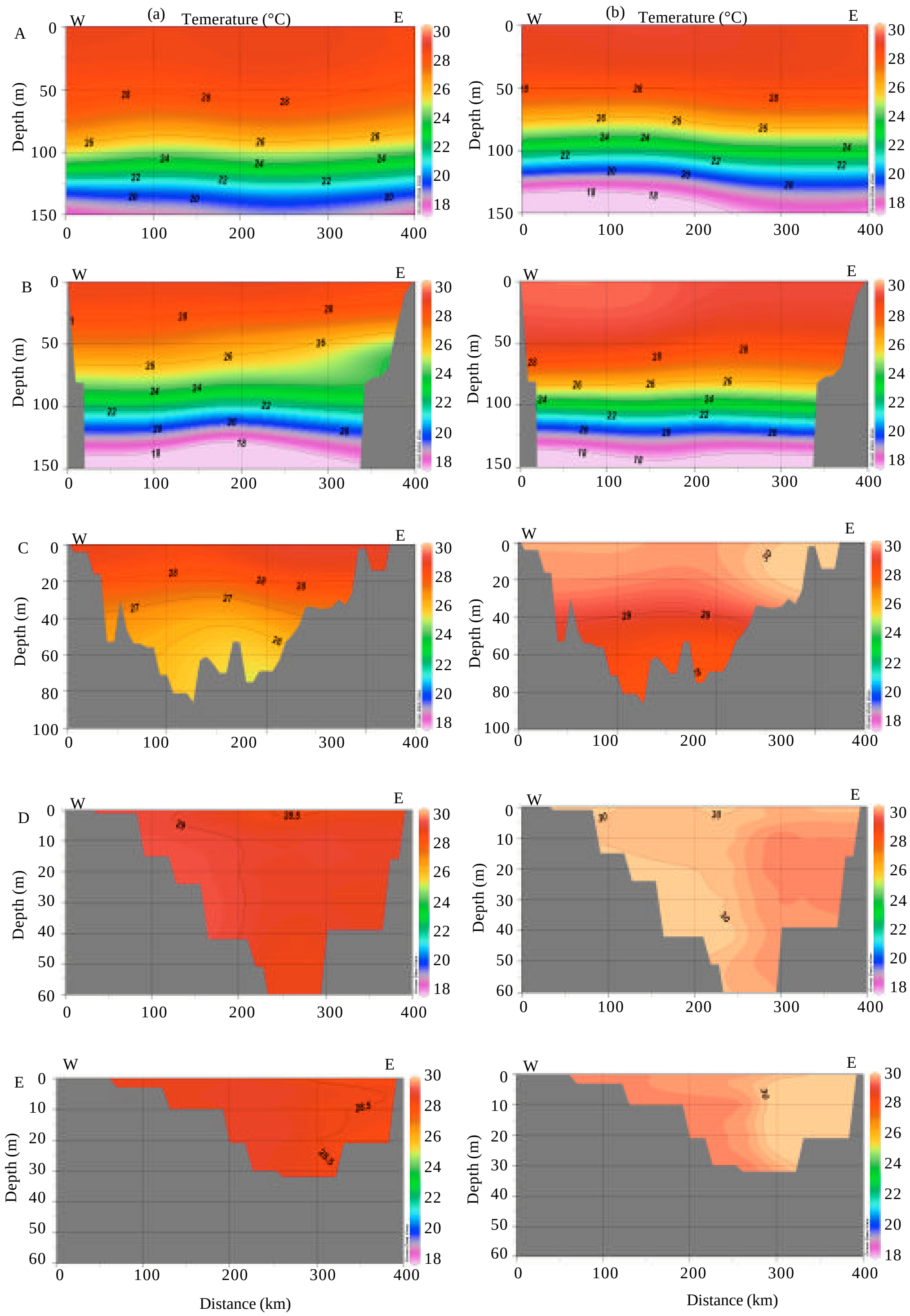

Fig. 4: Seasonal vertical variation in water temperature based in section of polygon A, B, C and D at the Malacca Strait area. The x and y scale for distance and depth varies for each section. (a) Northeast Monsoon (Nov-Dec-Jan-Feb) and (b) Southwest Monsoon (May-Jun-Jul-Aug). N: North, S: South, E: East, W: West

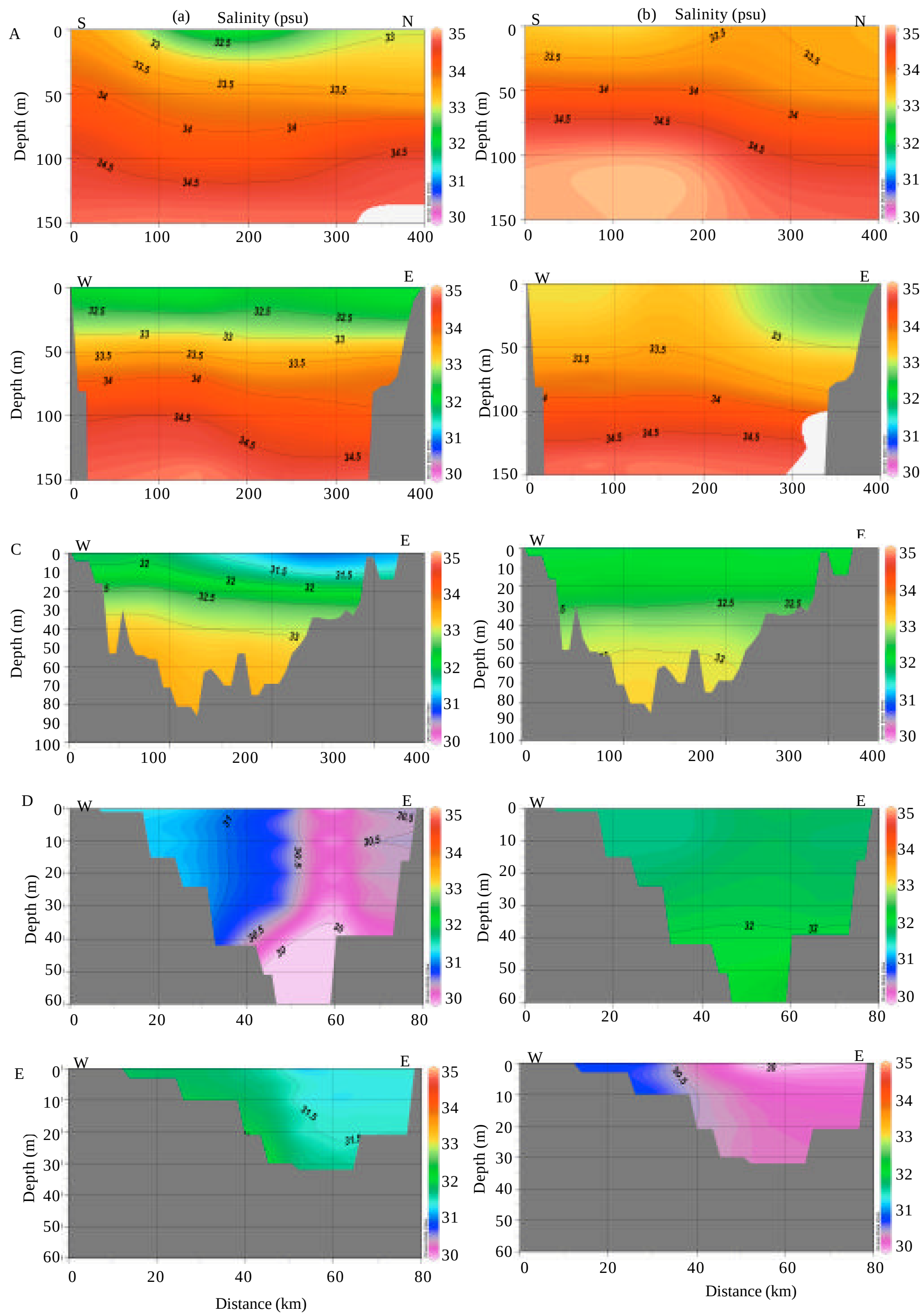

Fig. 5: Seasonal vertical variation in water salinity based in section of polygon A, B, C and D at the Malacca Strait area. The x and y scale for distance and depth varies for each section. (a) Northeast Monsoon (Nov-Dec-Jan-Feb) and (b) Southwest Monsoon (May-Jun-Jul-Aug). N: North, S: South, E: East, W: West

of river discharge where the surface salinity was much lower compared to stations at the North. The low salinity values were also observed in the section E of Fig. 5b. However, these results need to be studied further for clear understanding.

Oxygen saturation: Figure 6 shows the seasonal vertical variation in oxygen saturation (%) for sections A-E in the Malacca Strait region. During Southwest Monsoon, the upper layer values in sections A-C were ~2.25%, higher than the Northeast Monsoon, around 2% oxygen saturation. It was assume that the blowing of Southwesterly wind increase the Northern strait surface movement and lead to the greater diffusion of oxygen into the Strait. The recommendation is almost similar to the upper layer in the Southern part of the Strait. The changes of wind direction to the Northeasterly wind in Northeast Monsoon result the oxygen saturation values for sections D and E were ~2.25%, higher than the Southwest Monsoon, 2.15 and 2.1%, respectively.

Stratification: High water temperature and low water salinity values formed the less dense water stratification in the surface layer of the Strait of Malacca. Oxygen saturation data provide an additional observation of the strait stratification, as it cannot be seen clearly from salinity data contour plots. From Fig. 4 and 6, a stratification layer can be observing in sections A and B due to high depth factor. A generally well-mixed system in section D and E occurred in smaller and shallower Southern sector of the Strait that their depth ranges were less than 60 m. A wind mixing and the sunlight reach the bottom of the shallow sector also contributed to the vertical mixing layer process.

The seasonal vertical sections were more stratified with warmer water on the surface. In Southwest Monsoon period, warm and calm conditions cause the layer becomes more resistant to mixing by surface winds (Fig. 4b, 6b). When Northeast Monsoon period comes (Fig. 4a, 6a), the water cools and concurrently with the rainfall events, greater movement on water surface due to the action of waves and strong winds (Chua *et al.*, 2000) water tend to mix and stratification is less stabilizing.

Overview: Peninsular Malaysia can be likely anticipated high rainfall during Northeast Monsoon season. This result to the increase of high river discharges from West coast of Peninsular Malaysia contributing to the flow of fresh water to the strait which we can see from Fig. 3a (salinity) and sections C and D of Fig. 5a. A previous study by Siegel *et al.* (2009) and Baum *et al.* (2007) also stated that the discharge of Siak River System-East Sumatra increase in Northeast Monsoon period.

The drier seasons during Southwest Monsoon season may result in the increased values of surface water temperature as shown in Fig. 3b and 4b (Chua *et al.*, 2000). In addition, the blowing of Southwesterly wind may push high saline water from Indian Ocean and Andaman Sea (Fig. 3b, 5b; sections A and B) intruding the strait (Ibrahim and Yanagi, 2006) and considerably enhance the diffusion of dissolve oxygen around the Northern sector (Fig. 3b).

These findings of the current study are consistent with those of Ibrahim *et al.* (2003), who found a pattern of changes in water temperature, salinity and dissolved oxygen was highly influenced by seasonal variation in the Strait of Malacca. One of the issues that emerge from these findings is the strong influence of freshwater input and intrusion of Andaman Sea during Southwest Monsoon may affect the movement of any materials and pollutants around the Strait. It can thus be suggested that the pollutant behavior also can be identified with the interaction of

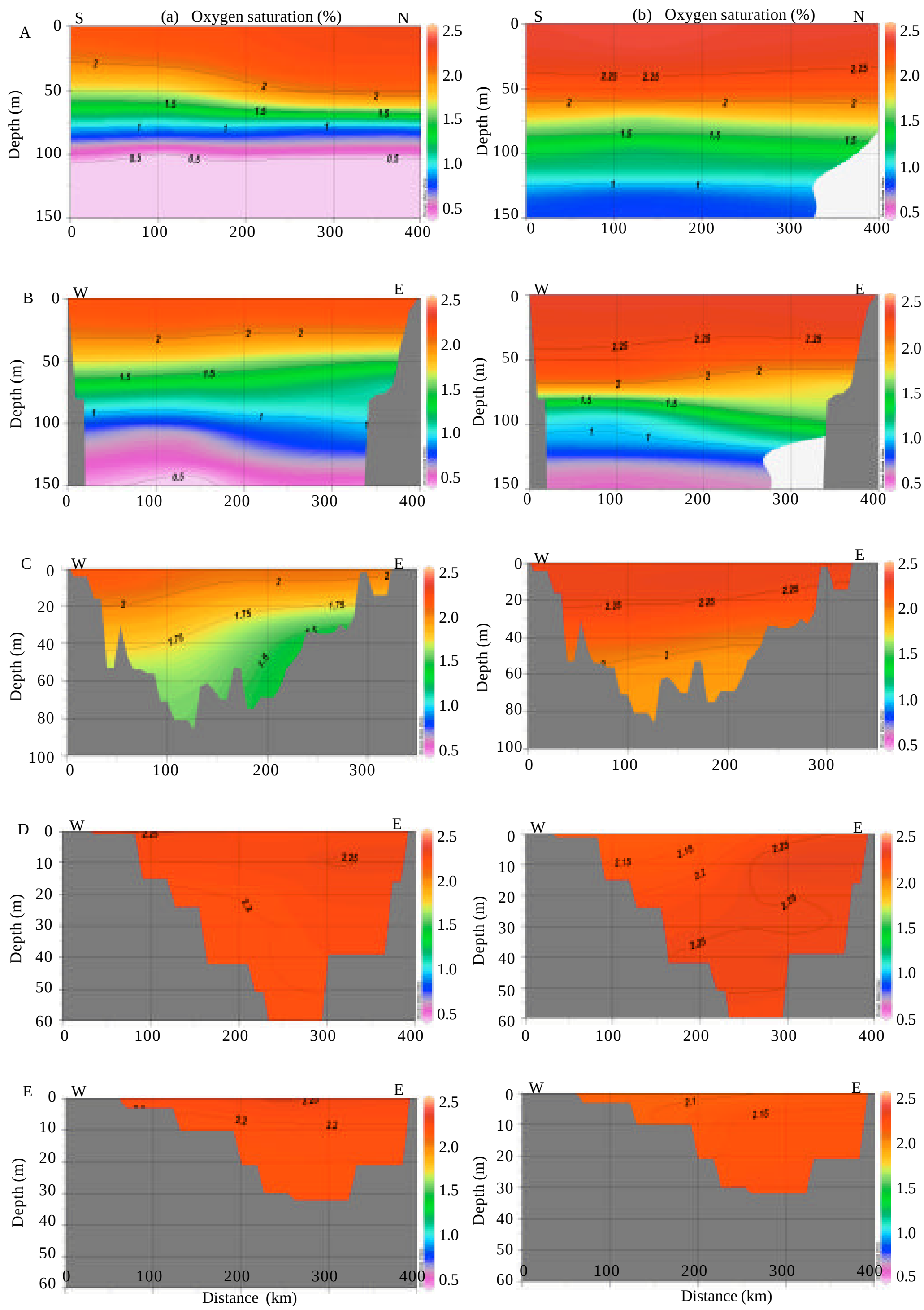

Fig. 6: Seasonal vertical variation in dissolved oxygen based in section of polygon A, B, C and D at the Malacca Strait area. The x and y scale for distance and depth varies for each section. (a) Northeast Monsoon (Nov-Dec-Jan-Feb) and (b) Southwest Monsoon (May-Jun-Jul-Aug). N: North, S: South, E: East, W: West

different water stratification condition. The pollutants can be likely to mix with less water stratification in Northeast Monsoon. In contrast, during strong stratification in Southwest Monsoon, the pollutants were prone to remain on the surface and easily moved to other place.

CONCLUSION

Water mass properties, which comprise water temperature, salinity and dissolved oxygen in the Strait of Malacca, were found to be highly influenced by the Monsoon season. This maybe affected by factors like higher river discharges and Monsoon winds causes the variable pattern of change in these parameters. The data demonstrates the significant low salinity input during the Northeast Monsoon season from Peninsular Malaysia. During the Southwest Monsoon period, high saline water from the Andaman Sea enters the strait from the Northern sector. Warmer conditions in Southwest Monsoon may possibly strengthen the stratification on the surface Strait especially in the Northern sector. On the other hand, the shallow and narrow of the Southern section are more homogeneous in entire season signifying finer mixing. The current study was not specifically analyzed a density variables to evaluate factors related to stratification. This further study can improve the better understanding of seasonal water mass variation in the Strait of Malacca.

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