Acta Oceanol. Sin., 2019, Vol. 38, No. 1, P. 38–47
https://doi.org/10.1007/s13131-019-1368-8
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

Exploring thermocline and water masses variability in southern South China Sea from the World Ocean Database (WOD)

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Received 13 November 2017; accepted 23 March 2018

Abstract

Study about water characteristics (temperature and salinity) from the World Ocean Database (WOD) was conducted in the area of southern South China Sea (SSCS), covering the area of 0°–10°N, 100°–117°E. From interannual analysis, upper layer (10 m) and deep water temperature (50 m) increased from 1951 until 2014. Monthly averaged show that May recorded the highest upper layer temperature while January recorded the lowest. It was different for the deep water which recorded the highest value in September and lowest in February. Contour plot for upper layer temperature in the study area shows presence of thermal front of cold water at southern part of Vietnam tip especially during peak northeast season (December–January). The appearances of warm water were obviously seen during generating southwest monsoon (May–June). Thermocline study revealed the deepest isothermal layer depth (ILD) during peak northeast and southwest monsoon. Temperature threshold at shallow area reach more than 0.8°C during the transitional period. Water mass study described T-S profile based on particular region. Water mass during the southwest monsoon is typically well mixed compared to other seasons while strong separation according to location is very clear. During transitional period between northeast monsoon to southwest monsoon, the increasing of water temperature can be seen at Continental Shelf Water (CSW) which tend to be higher than 29°C and vice versa condition during transitional period between southwest monsoon to northeast monsoon. Dispersion of T-S profile can be seen during southwest monsoon inside Tropical Surface Water (TSW) where the salinity and temperature become higher than during northeast monsoon.

Key words: southern South China Sea, upper layer temperature, northeast monsoon, southwest monsoon, thermocline, water mass

Citation: Johari Afifi, Akhir Mohd Fadzil. 2019. Exploring thermocline and water masses variability in southern South China Sea from the World Ocean Database (WOD). Acta Oceanologica Sinica, 38(1): 38–47, doi: 10.1007/s13131-019-1368-8

1 Introduction

World Ocean Database (WOD) is one of the ocean climatology program under National Oceanic and Atmospheric Administration (NOAA). It was compiled at NOAA's National Oceanographic Data Center (NODC) in Silver Spring, Maryland, USA. This database consist of physical oceanographic datasets which include over 12 million water temperature datasets and 5.6 million water salinity datasets. Data from WOD is beneficial because it is suitable for wide range of spatial and temporal studies. Availability of data is started from the year 1900 until 2014. The data in WOD is updated for every 4 years. The validity of data is non-deniable because this data is required with full set of quality control. At global distribution, started from 1974, the number of data provided increased until 2013. Data from WOD are very reliable for multi-decadal study (Seidov et al., 2015; Yashayaev and Seidov, 2015). Referring to physical oceanography purpose, the most important parameter is temperature and salinity. Datasets in WOD is sorted according to geographical or yearly. The extraction of data can be downloaded for free with this link: https://www.nodc.noaa.gov/OC5/WOD/prwod.html. In the study area, the datasets is fairly distributed. It creates an opportunity for research about variability of water temperature and salinity in study area. The study is done including the water temperature profile and classification of water mass that present in SSCS. The southern South China Sea (SSCS) is highly influenced by two major monsoons which is northeast and southwest monsoon. Study about seasonal changes due to water temperature and salinity dynamics is done based on the seasonal changes. According to Wyrtki (1961), seasonal variability in SSCS is divided into six periods as described in Table 1. The study done by previous researchers always regarding to transitional period, but there was no fixed classification of each period from them.

SST in SSCS usually colder during northeast monsoon compared to southwest monsoon season (Tan et al., 2002). This is because of the water current moving from cold area which located at northern part and flooded to the study area (Akhir et al., 2014). Large spatial and temporal study in SSCS about the dynamical SST is done by Haghroosta and Ismail (2017) which covered about year 1991–2011 from generating southwest monsoon until peak northeast monsoon season. During northeast monsoon season, east coast of Peninsula Malaysia (ECPM) and west coast of Sabah and Sarawak recorded the differences in SST value between high and low latitude region. In this case, low latitude region recorded the low SST and high precipitation rate. While at the center region of SSCS, low latitude region recorded high SST and low precipitation rate. Water intrusion from the Karimata Strait occurs during generating period of southwest monsoon (May–June). This lead to the increasing of SST in SSCS especially

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Table 1. Separation of seasons according to month

Month	Period	Season
Feb.	weakening northeast monsoon	trasnsitional northeast–southwest monsoon
Mar.		
Apr.		
May	generating southwest monsoon	
Jun.		
Jul.	southwest monsoon	peak southwest monsoon
Aug.		
Sep.	weakening of southwest monsoon	trasnsitional southwest–northeast monsoon
Oct.	generating northeast monsoon	
Nov.		
Dec.	northeast monsoon	peak northeast monsoon
Jan.		

near ECPM (Akhir et al., 2015; Daryabor et al., 2015). Previous study has described the dynamical changes of water temperature and salinity features by using satellite and remote-sensing data. It is good because the spatial and temporal coverage is larger. However, there is a limitation of study by using these methods because of the inhibition from studying the temperature or salinity by each depth. Hence, observation of vertical water mass (T-S) distribution provided by WOD is very precious knowledge about water mass variability in SSCS, and the thermocline study.

Thermocline properties differ according to location and seasons. Previous study regarding water characteristics in SSCS are mainly focused on near shore area. After northeast monsoon season, thermocline properties usually disappear especially in the area of Terengganu and Pahang area (Roseli and Akhir, 2014; Roseli et al., 2015). Compared with Johor coast, thermocline features is observed during both northeast monsoon season and weak northeast monsoon season (Akhir and Yong, 2011). Unfortunately, there are no studies during peak northeast monsoon which is from December until January. Moving to the next period, stratification of water temperature is prominent during early southwest monsoon season especially in Pahang and Terengganu area (Husain et al., 1985; Chark et al., 1986; Saadon et al., 1998; Roseli et al., 2015; Zainol and Akhir, 2016a). Compared with Sabah and Sarawak waters, the thermocline range is lower than ECPM (Saadon et al., 1998). There were two types of water temperature stratification which is deep water stratification and vertical stratification. For deep/vertical water stratification, it occurs in Terengganu/Pahang waters (Zainol and Akhir, 2016a). Just one study is conducted during weakening southwest monsoon which addressed in Terengganu waters. In this case, the thermocline layer is deeper when compared with weakening northeast monsoon period.

At nearby area which is Gulf of Thailand (GoT) and Malacca Strait, study by using data from WOD had been done by Buranapratheprat et al. (2016) and Amiruddin (2011). Study by Buranapratheprat et al. (2016) is just within the transitional period which is during 5–8 September 1995 and 24 April–17 May 1997. Differ with the study of Amiruddin (2011) which analyzed the data in the whole time period which is started from 1900 until 2014. However, both studies agree that the stratification of water temperature and salinity is higher during southwest monsoon than northeast monsoon. This is due to the low wind speed which stabilize the stratified water column. When compared by locations, the northern part of Malacca Strait present the high saline water compare with the southern part because of the intrusion of water from the Indian Ocean during southwest monsoon while low saline water at southern part during northeast monsoon was caused by the heavy rainfall and river discharged from mainland. Another observation can be seen in GoT which both stratification of water clearly seen during both northeast and southwest monsoon season. Complex stratification is observed during the northeast monsoon which probably caused by the inlet water from SCS toward GoT mouth.

Study regarding the water masses and thermocline by using *in situ* data with large temporal and spatial gap is very seldom. The only previous study conducted in this framework was by Zheng et al. (2016) using datasets from WOD in the West Pacific Ocean. But, the study area in SSCS by Zheng et al. (2016) does not covered below 5°N. Besides, T-S scatter diagrams in SSCS is just similar as in whole SCS in his study. But, it was done without comparisons among the seasonal changes. Differ with thermocline studies, the precision of study including the threshold between shallow and deep water during peak northeast and southwest monsoon is done. Hence, there is the gap to be filled which is the narrow description of T-S and thermocline in study area with seasonally averaged from 1950–2014 in each period. Hence, this paper is the pioneer study to reveal the study gap of thermocline features in SSCS since previously research mostly done at near shore area. Besides that, thermocline features can lead us to significant study on El Niño–Southern Oscillation (ENSO) effects. Since SSCS is a semi-enclosed basin, study about thermocline features can describe more about dynamical pattern with related nearby waters such as Sabah Basin which typically colder throughout the year.

This study is done to describe the water characteristics variations in SSCS by using data from WOD. It will describe the water temperature and water mass characteristics throughout the seasonal changes with averagely started from 1919 until 2014. Six seasonalities is chosen for this study which is weakening northeast monsoon, generating southwest monsoon, peak southwest monsoon, weakening southwest monsoon, generating northeast monsoon, peak northeast monsoon. Water temperature trend and pattern will be described, and some location is focused on thermocline and water mass study. This study will provide the overall view of seasonality changes on water characteristics variability in SSCS. The advantage of using the data from WOD is that the elaboration and precision of water temperature and water mass study can be done without considering the distortion part such as cloud cover as faced by remote-sensed study.

2 Methodology

2.1 *Study area*

The southern South China Sea is a semi-enclosed basin which located at 0°–10°N, 100°–117°E. The bathymetry which located at Sunda shelf in SSCS varies from 50 to 100 m (Fig. 1) while the deepest bathymetry is located at northwest part of Sabah and the depth can reach 5 000 m. Some straits play major roles in connecting water intrusion from other seas such as Karimata Strait (connecting Java Sea). While refer to nearby area, northeast part of SSCS (Sabah waters) is connected with Sulu Sea. GoT is the part of SSCS. It is the semi-enclosed shallow water bodies which connected to the southwest of SCS.

2.2 *Data collection*

Data collection is done by extraction of datasets from WOD.

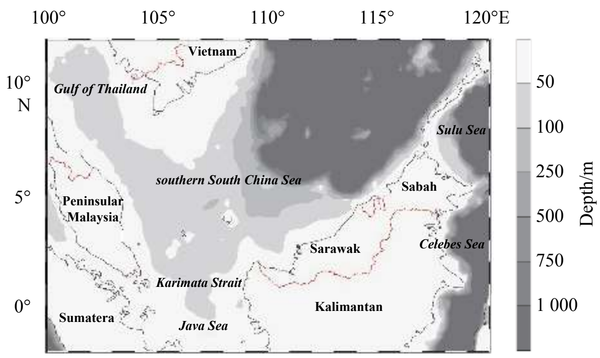

Fig. 1. Bathymetry map of SSCS. Typically shallow along ECPM and west coast of Sabah-Sarawak shore (50 m). The depth range of SSCS is between 50 and 100 m. Approaching northeast part, presence of deep water basin (~1 000 m).

WOD provide large scale for spatial and temporal datasets. The availability of data started from 1919 until 2014. Data provided by WOD was chosen based on geographical location. From the extracted data based on our chosen domain, there is 23 252 number of datasets distributed in the study area (Fig. 2). All 23 252 is the combination from CTD, MBT, OSD, PFL, XBT and Surf All. The data presented from 1919 until 2014. By comparing all the datasets, MBT recorded the highest number followed by OSD, XBT, PFL, CTD and Surf All (Table 2). Since we are focusing only on salinity and temperature data in this study, we discover that from overall data available, 32% contain both temperature-salinity data.

The distribution of data is random while the compactness is presented in particular area. Through the month, the compactness is high from 2°N, 105°E towards 10°N, 110°E. While focusing on the east coast of Peninsula Malaysia, high compactness can be seen every month and it just present in 1°–3°N, 104°–105°E. Well high compactness can be observed at Vietnam tip (8°–10°N, 105°–110°E). However, at Sabah water (6°–8°N, 115°–117°E) poses the fair distribution throughout the month. By combining the datasets based on seasonality, it increases the monthly compactness by twice. Some particular area such as at east coast of Johor (2°–3°N, 104.5°–105.5°E) shows the high compactness of datasets. Since it was located at shoreline area, the datasets are very reliable for primary productivity study such as upwelling features. Number of datasets for T-S study is lower than datasets with Temperature datasets (Fig. 2b) and distribution of datasets in the study area is poor throughout the month (n=6 797). However, high compactness of T-S datasets is observed across 2°N, 105°E towards 10°N, 110°E, with the same location of temperature datasets. Compactness at Sabah-Sarawak shares almost similar pattern of distribution. Temperature dataset, combined with several months dataset has increase the compactness which is a better representation for seasonality analysis. In this study, we will focus at few connecting region to the SSCS such as the Karimata Strait, center of SSCS and northern Sabah waters which are very important in comparing the water mass dynamic of study area.

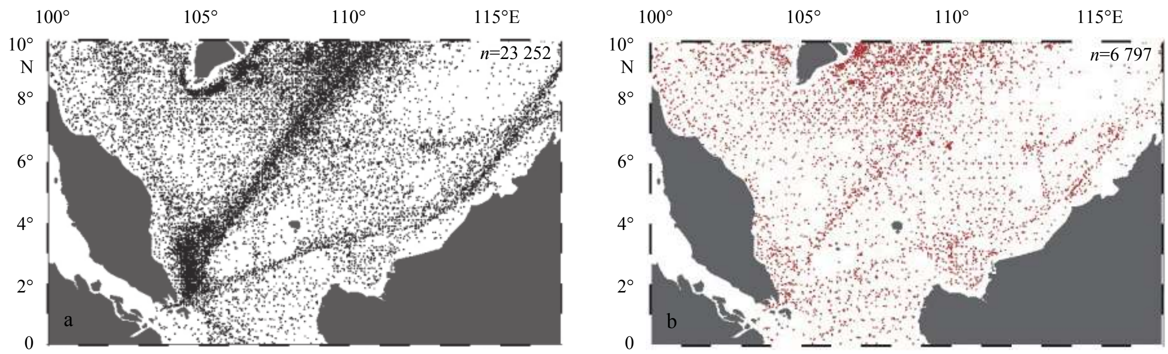

Fig. 2. Distribution of datasets present in SSCS (a, n = 23 252), while (b) is the dataset which present both temperature–salinity data (n = 6 797). Datasets compactness is high in particular region such as in east coast of Johor, Vietnam tip and across the SSCS.

By looking at timeline series of datasets (Fig. 3), the rapid increasing of datasets occurs from the year 1940 until 1960 for temperature datasets. The highest recorded in 1960–1969 (n=7 000). This is due to the international effort on the oceanographic survey mainly being supported by the US navy through the NAGA Report expedition (Wyrtki, 1961). Then, the datasets number rapidly decreases until the year 2010–2016. This is when the national oceanographic capacity has taken place and although many data collection might have been done, but most of the data are owned by specific organization within the specific countries and are not available in the WOD. For T-S datasets, the increment started at year 1950–1959 until 1970–1979 and recorded the highest number of datasets (n=2 500). From 1970–1979 to 1980–1989, the number slightly decreased, then rapidly decreased until 2010–2016.

Table 2. Total number of datasets according to the types

Datasets	Total
CTD	211
MBT	9 334
OSD	6 994
PFL	226
XBT	6 909
Surf All	7
Total	23 252

Figure 4 shows the number of temperature datasets throughout the year, separated by month. It shows the small difference number by monthly for each year. The highest number of datasets are recorded during 1966–1968, then decreased until 1979. The year 1980 recorded the high record again, while it directly decreased until the year after. Monthly averaged data is presented in Fig. 5. The highest number of temperature's datasets is recorded during December (n=2 051) while the lowest is in October (n=1 420). For overall observation, there is no difference

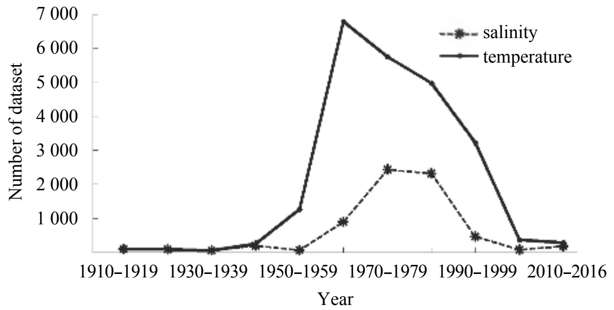

Fig. 3. Timeline observation of datasets number by decadal average. Throughout the time, datasets with both temperature and salinity parameter recorded the low number.

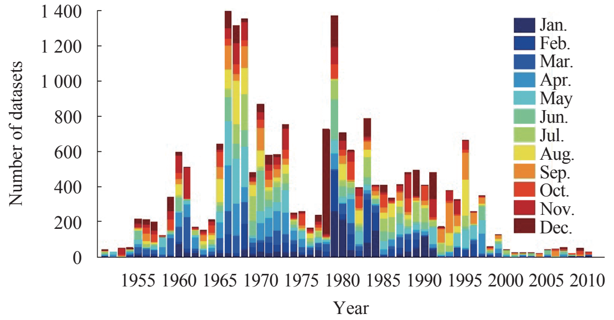

Fig. 4. Number of datasets of each month for every year.

more than 1 000 datasets among the months. This is the valuable finding because it is the northeast monsoon season from December to January and the wind speed is relatively high, and limited data are available from sampling activity. Hence, high distribution of datasets during both monsoon seasons provide very significant input to the analysis in this study.

For T-S datasets, December recorded the highest (n=1 052) while May recorded the lowest (n=352). Drastic decrease occurs

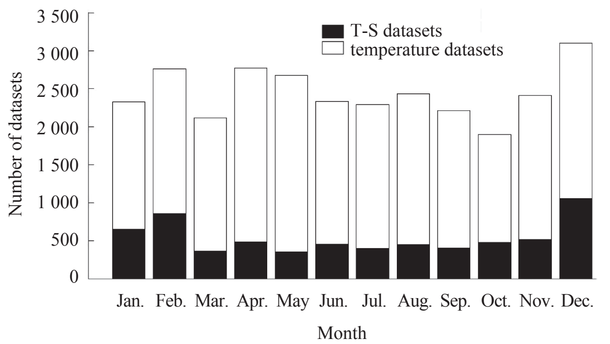

Fig. 5. Monthly average number of datasets from 1919 to 2014.

between February to March while drastic increment from November to December. Along March until November, just slightly changes of datasets number which not exceeding 200 among them. By comparing of percentage between T-S datasets to temperature datasets, it recorded the highest percentage in December (51%) while the lowest in May (15%). The second highest percentage is recorded in February (45%) followed by January (39%), October (34%), June (24%), August and September (22%), March, April and July (21%).

2.3 *Data processing and quality control (Fig. 6)*

The selected "square map" covered the area within 0°–10°N, 100°–120°E. Datasets by "geographically sorted" was selected because this study intend to focus at a very specific study domain for data processing analysis. For the depth profile, "standard depth level" method was selected. All depth profile recorded by observant had been corrected by interpolation of 5 m depth for each level during data compilation and quality control by WOD13 team.

Data distribution is plotted by using Ocean Data View (ODV) software. Inside the square maps, there are 25 864 datasets in total. The elimination of datasets was done to exclude the datasets presents in the Malacca Strait, upper than 10°N and 117°E, Sulu Sea and Java Sea. However, some of datasets presents in the mainland such as that at the east coast of Peninsula Malaysia, Sabah-Sarawak and Vietnam. After the elimination, the datasets reduced about 10%. The elimination of data combination of all datasets files is done to get the availability of datasets according to spatial and temporal study. After the datasets is plotted, ODV represents the total number of datasets according selective spatial and temporal. During extraction of datasets, the limitation of datasets reading is done by refer to the range by previous author.

ODV also filtered the duplicated datasets, besides present the number of datasets directly. During data processing by ODV, exception of non-selective parameter (other than temperature and salinity) is done. Then, observation of datasets compactness is done by considering spatial-temporal study. Exportation of datasets according to particular time is also done by using ODV. The new datasets file can be saved as in "text" or "netcdf" file. Quality control is done with ODV software. The range for depth, temperature and salinity is precise during that process according to previous research.

2.4 *Data analysis*

Data analysis was conducted using ODV and MatLab software. ODV software is very initiative for data plotting and quantitative analysis. Firstly, all 6 types of datasets which are CTD, MBT, OSD, PFL, XBT and Surf All were analyzed as shown in Table 2. Secondly, comparisons of datasets percentage based on the particular parameter were done. By using ODV software, selected datasets which present temperature data or both temperature-salinity data were recorded. Then, the percentage of it was

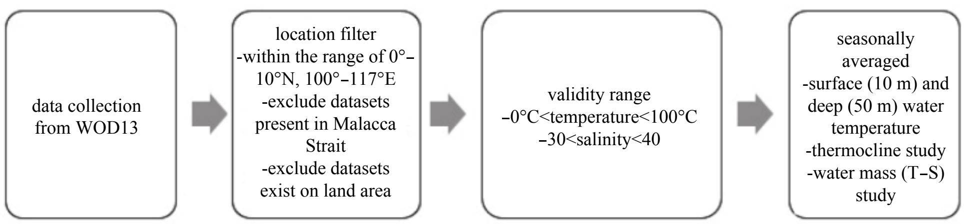

Fig. 6. Flowchart of method used in data analysis and quality control.

done by using MatLab. Thirdly, comparisons for number of datasets by monthly and seasonally averaged were done by ODV, then plotted by using MatLab. Forthly, distribution of datasets in study area was plotted by using ODV. Hence, the decision of seasonally averaged study was done in this study rather than monthly averaged.

Water temperature characteristics and variations study are the main focus in this study. So, analyzing trend and pattern will be the main interest for the study area. Both Matlab and ODV serve different purpose in achieving these objectives. We look into the annual water temperature by seasonally average for upper layer (10 m) and bottom (50 m) from 1960 until 2014 using MatLab. Then, contour plot of upper layer temperature was plotted by using ODV to analyze the seasonal pattern. For thermocline and water mass study, the selected location was done based on the high compactness of datasets and coincide with nearby area such as GoT, Karimata Strait and Sulu Sea. For more constructive result and discussion, 4 boxes with 0.5°×0.5° resolution was selected for temperature-depth. For water mass study (temperature-salinity), each box resolution is 3°×3° by seasonally averaged. Scatter plot for water mass study was done in MatLab to observe the features according to the location by seasonality variations.

3 Results and discussion

3.1 *Water temperature features*

Study regarding the annual water temperature was done from the year 1951 to 2014. This was chosen specifically because the number of datasets provided for each year are well distributed in space and time, besides the highest number of stations it has. Generally, upper layer temperature (represented at 10 m depth) is constantly higher than the deep water temperature (50 m depth) throughout the years. The anomaly water temperature for surface is 28.5°C while 26.8°C for 50 m depth.

For upper layer temperature (Fig. 7a), 39 out of 64 selected years are below the temperature anomaly. From the year 1982 and onwards, the upper layer temperature is higher than anomaly. The higher upper layer temperature was recorded in 2014 (29.9°C) while the lowest was recorded in 1984 (26.7°C).

For deep water temperature (Fig. 7b), 35 out of 64 selected years showed water temperature lower than anomaly. The pattern is different from upper layer temperature, where the longest year of high and low water temperature than anomaly occurs only for 4 years. Hence, the deep water temperature remains cold just not like upper layer. The highest deep water temperature was recorded in 2005 (29.7°C) while the lowest was recorded in 2014 (24.8°C). The trendline shows that the increase of both SST and deep water temperature which indicate the global warming is happening.

The data from 1919 until 2014, upper layer temperature and deep water temperature was averaged according to month (Fig. 8). The lowest upper layer temperature was recorded in January (26.3°C) and the highest was in May (29.5°C). Upper layer temperature increases drastically from January until May. Post southwest monsoon (started from September) showed decreasing pattern of SST, but start to increasing during post northeast monsoon in east coast of Peninsula Malaysia (Akhir et al., 2014). After May, it decreased until August. From August to October, the surface water temperature remain constant at 29°C. Then, there was a rapid drop from October to December.

For deep water temperature, the trend was slightly different from the surface water temperature. The lowest temperature was recorded in February (25.5°C) and the highest was in September

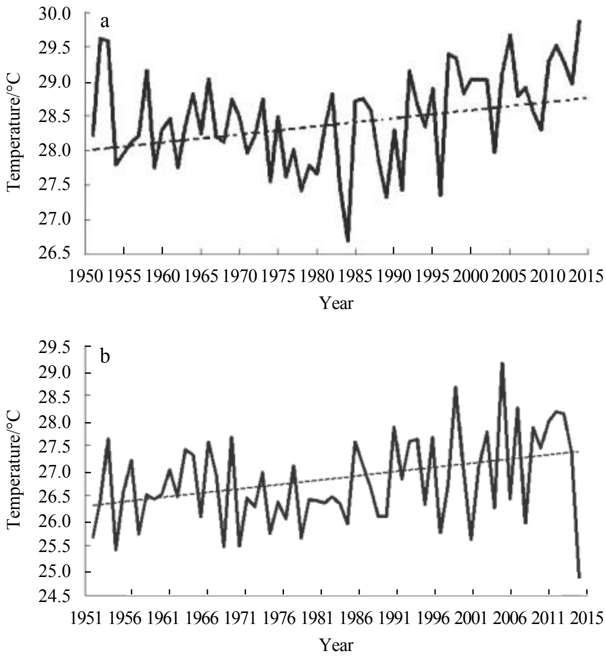

Fig. 7. Inter-annual data for upper layer (a) and bottom (b) temperature at SSCS from 1951 to 2014 indicating the increasing of trendline based on the linear plot (dotted line).

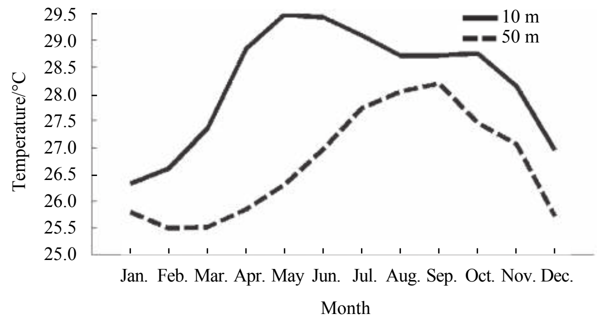

Fig. 8. Monthly average temperature for sea surface and deep water.

(28.2°C). Then it decreases slightly from January to February, before increased until September.

3.2 *Thermal front in SSCS*

During northeast monsoon, upper layer temperature in the study area along the east coast of Peninsular Malaysia (105°E), is relatively cold (Fig. 9a) which range between 26°C and 29°C. Cold water tongue at Vietnam tip will usually flooded into the east coast of Peninsula Malaysia (Kok et al., 2015). SST in GoT also recorded the lowest upper layer temperature during northeast monsoon compare to other seasons. Strong southwestward wind during the northeast monsoon bring the cold air from northern South China Sea. During this period, the east coast and northern part of Peninsula Malaysia gain high precipitation rate and cloud cover enhance the decreasing of SST (Marghany, 2012; Akhir, 2012). Cold upper layer temperature is also prominent at the west coast of Sabah along northeast monsoon season (Abdul-Hadi et al., 2013). Different condition was observed at the west coast of Sarawak, which poses high value of SST (29°C).

Weakening of the northeast monsoon season which usually

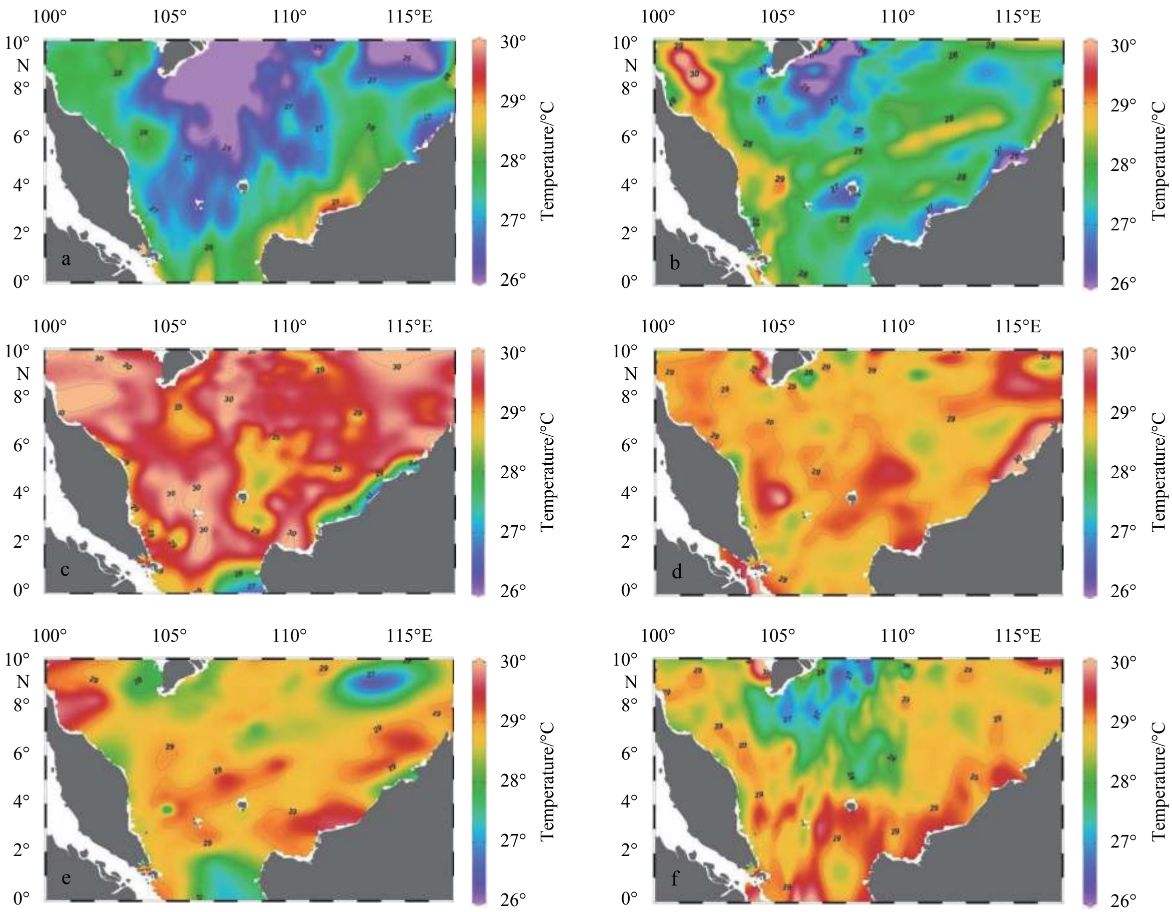

Fig. 9. Upper layer temperature contour plot in SSCS according to seasonality. a. Peak northeast monsoon, b. weak northeast monsoon, c. generate southwest monsoon, d. peak southwest monsoon, e. weak southwest monsoon, and f. generate northeast monsoon.

start during February subsequently increase the upper layer temperature in the study area gradually (Fig. 9b). With the cold water tongue fully diminished, GoT and along the east coast of Peninsula Malaysia start to record high upper layer temperature value (~29°C to 30°C). The whole region of SSCS recorded the range between 28°C and 29°C. However, the coastal water of Sarawak present the opposite upper layer temperature features, where the upper layer temperature recorded a cooler value (26°C) than during the northeast monsoon months.

With regard to the generating southwest monsoon season, overall upper layer temperature within the domain was warmer and high value was recorded (Fig. 9c). Upper layer temperature was averaged at 30°C, except for Sarawak west coast, where the value is lower (~26°C to 27°C). This was a result of low precipitation rate during May and June that initially produce strong radiation from sunlight and surface heat flux. During this phase, the northeasterly wind speed also started increased. Large sea surface heating and weak sea surface wind during April and May usually develop stratification through the water column (Yanagi et al., 2001), which will be discussed further in Section 3.3.

During the peak southwest monsoon season, the upper layer temperature was not as high as during the transition season (Fig. 9d). The value decreased and the range was between 28°C and 29°C. During this season, water intrusion from the Karimata Strait occurs which caused by northward wind stress. Northward wind stress generates water current from Karimata Strait and along the east coast of Peninsula Malaysia. Detail about the dynamical pattern of wind and water current was proved by Kok et al. (2015). South to southwesterly winds were dominated alongshore of ECPM. High wind speed reached a peak value in August while decreased in September. In ecological impact, cold water from the bottom part of coastal is moving upward and known as upwelling. Upwelling is a process of water moving from subsurface to the surface and brings high nutrient and cooler water to the surface. Evidence from study by Akhir et al. (2014) and Kok et al. (2015) indicates the coastal upwelling occurs between June and August along the east coast of Peninsula Malaysia. This situation can be seen in Fig. 9d at 3°N and 5°N along the east coast of Peninsular Malaysia.

During the weakening of the southwest monsoon season (Fig. 9e), the upper layer temperature is typically lower than that of the initial season. Warm water column (30°C) start to diminish while cooler water (28°C) start to reappear. However, the west coast of Sarawak was still relatively warm than the surrounding area.

Generating northeast monsoon season (Fig. 9f) shows the cold water tongue at Vietnam tip flooded southward. The cold water started to take over from 4°N to 10°N. Cold water tongue range between 27°C and 28°C, not colder as in peak northeast monsoon season. Besides, GoT also faced the cooling effect during this season. Upper layer temperature value in GoT decreased to 29°C.

3.3 *Thermocline study*

Four locations are selected for thermocline study; near the GoT, Karimata Strait, central SCS and Sabah (Fig. 10). These locations are selected based on the areas that possibly have significant thermocline changes during the northeast and southwest monsoon season. Besides, the selected areas also are the places which are highly exposed to the water from the northern SCS. The resolution for each box is 0.5°×0.5°.

The data used for the thermocline study are the ILD data. The data was selected from 1919 to 2014 and were averaged by season. Study by Qu et al. (2007) found the MLD in SCS do not exceed 40 m throughout the year. In order to do a study of MLD, ILD can be used as the good proxy of MLD. ILD is the depth where the temperature almost constant. This study used ILD because of the lack of data for salinity parameter.

Usually, for deep/shallow water, the temperature decreased by 0.8°C/0.2°C from the temperature at reference level, 10 m, (Zheng et al., 2016). GoT and Karimata Strait usually located at shallow water with average depth of 70 m. GoT (Fig. 10a), during both peak northeast/southwest monsoon, recorded ILD of 20 m and the temperature is 27°C/28°C. In weakening northeast/southwest monsoon, ILD temperature is 27.8°C/28°C and the ILD is 5 m. During generating northeast/southwest monsoon, ILD's temperature is about 30°C with ILD depth of 5 m. Thermocline range in generating northeast monsoon is larger than in generating southwest monsoon which are 26–30°C and 28–30°C, respectively.

In the Karimata Strait (Fig. 10b), ILD is almost constant until the bottom during peak northeast and southwest monsoon season. However, southwest monsoon season typically recorded the warm ILD (29.5°C) compared to northeast monsoon (27°C). Thermocline layer is started at 30 m depth for northeast monsoon, while in the southwest monsoon season the thermocline layer was almost absence. Both weakening phase of northeast and southwest monsoon presented similar characteristics as in northeast monsoon, which ILD was found until the bottom. Thermocline layer is significant during generating of northeast and southwest monsoon. During generating northeast monsoon, thermocline layer started at 25 m depth and the temperature range is 0.8°C. During the generating southwest monsoon, thermocline layer started at 15 m depth and the temperature range is 3°C.

Sabah waters (Fig. 10c) show the same temperature range of ILD for both northeast and southwest monsoon season, 29°C. However, ILD in southwest monsoon season is shallower (65 m) than in the northeast monsoon season (75 m). Thermocline fea-

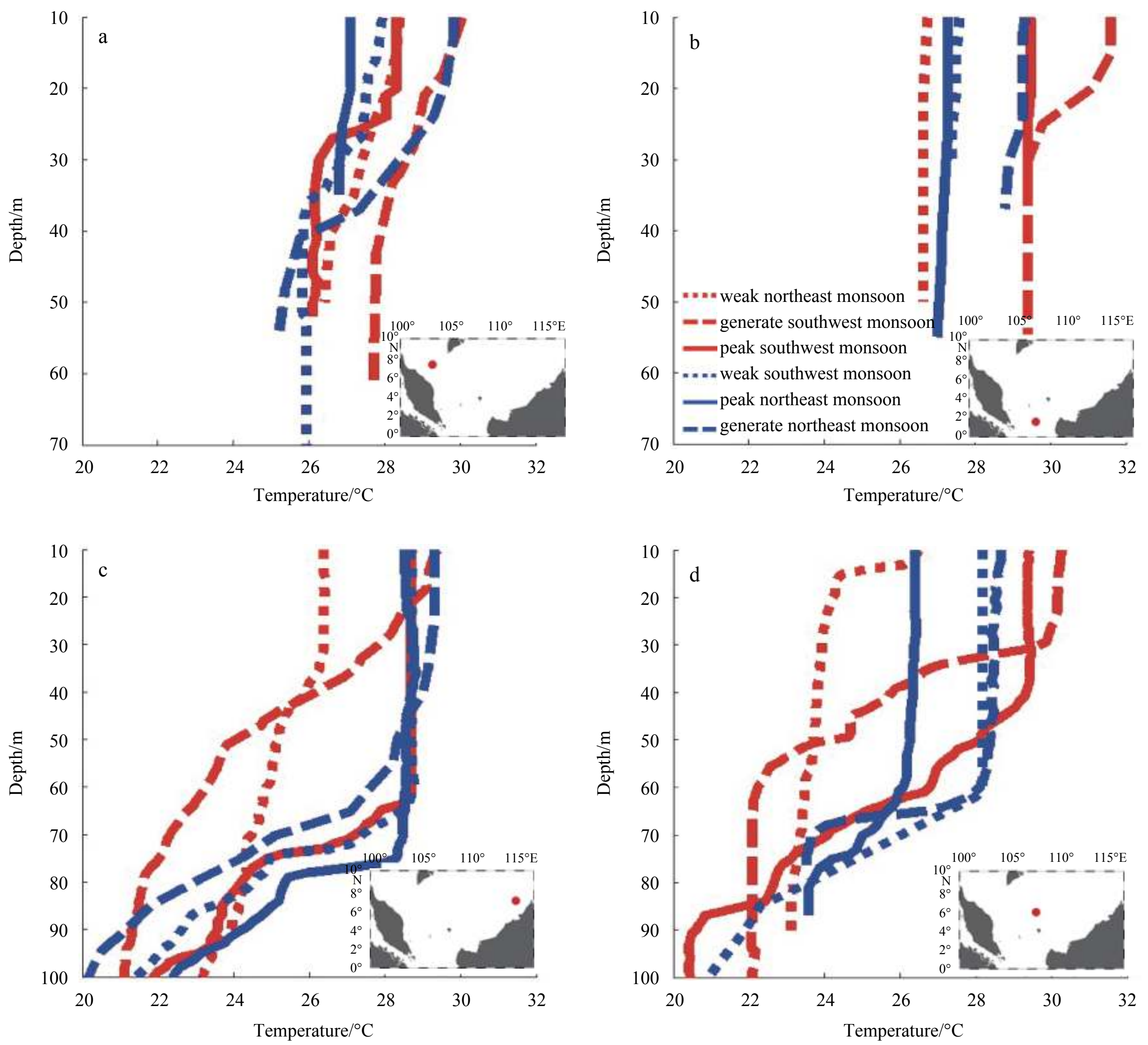

Fig. 10. Temperature by depth profile during 6 seasons selected in GoT (a), Karimata Strait (b), Sabah waters (c) and centre SSCS (d).

tures during the weakening southwest monsoon is similar as in peak northeast monsoon season. However during weakening southwest monsoon season, temperature profile shows the small range of thermocline (not exceed 1°C) compare to other seasons. During generating northeast (southwest) monsoon, the ILD started at 20 m (40 m) depth.

Big temperature gap between ILD was observed in the center SSCS (Fig. 10d) during peak northeast and southwest monsoon season. ILD in northeast (southwest) monsoon is 60 m (40 m) while the temperature is 26°C (29.5°C). However, ILD during weakening southwest monsoon and generating northeast monsoon is not different as much. In this case, ILD and its temperature is consistent which is 60 m in depth and 28°C from September until November. Weakening phase of northeast monsoon recorded the thermocline features started at 10 m, until it started constant at 15 m with 24°C. In generating southwest monsoon phase, ILD is about 30 m with temperature of 31°C.

From the selected locations, the ILD temperature typically decreased after the peak southwest monsoon until peak northeast monsoon, except GoT which increasing of temperature is recorded after peak southwest monsoon. Karimata Strait, Sabah water and centre SSCS recorded cooler ILD during weakening northeast monsoon compare to peak northeast monsoon. This is the part to be focused on because peak northeast monsoon season supposed to have the coldest water temperature throughout the season. Besides, Sabah waters recorded the same ILD temperature during peak northeast and southwest monsoon season. The highest temperature of ILD is recorded in Karimata Strait (32°C) during generating southwest monsoon, while the lowest recorded in Sabah waters (peak northeast monsoon) and centre SSCS (weak northeast monsoon) which is 29°C. In SSCS, the ILD is highly correlated with heat flux and its opposite with in NSCS area which correlated with speed and wind stress curl. Qu et al. (2007) found the domination of ILD in SSCS is due to the wind stirring and downward Ekman pumping. Generally, ILD in SCS is maximum in December and minimum in May. Deepening of ILD in SSCS started from June until November while from December until May, it becomes shallower. Deepest ILD in SSCS can reach down until 55 m depth. Study about ILD is very important because it provide huge insight of the role of MLD dynamics in climate variability in study area.

3.4 *Water mass (temperature–salinity) study*

Study of water mass was done within similar temporal and spatial range as thermocline study. But, adjustment for spatial range is done by enlarging the selected location. The area covered for each locations is 3°×3°; larger than the thermocline study (0.5°×0.5°). This adjustment is done because of poor distribution of temperature and salinity datasets in the area.

Classification of water mass is done by referring to study by Arsad and Akhir (2013). In this case, 8 classes of water masses are described in the study area including Continental Shelf Water (CSW), Open Sea Water (OSW), Seasonal Thermocline Water (STW), Tropical Surface Water (TSW), Maximum Salinity Water (MSW), Permanent Thermocline Water (PTW), North Pacific Intermediate Water (NPIW) and Deep Water (DW).

New finding found in this study is the new range of water temperature for CSW. Study by Arsad and Akhir (2013) stated the range of temperature for CSW was 29–31°C. However, in this study the temperature ranged from 27°C to 29°C and the salinity ranged from 30 to 32.5.

The GoT is located between the Vietnam tip and the east coast of Peninsula Malaysia with average depth of less than 100 m. This area receives large total river discharges throughout the year (Buranapratheprat et al., 2016). According to Fig. 11, the water at the GoT was dominated by CSW water mass. During the northeast monsoon, the CSW in the GoT were cooler and fresher than in the southwest monsoon season. It might be due to the

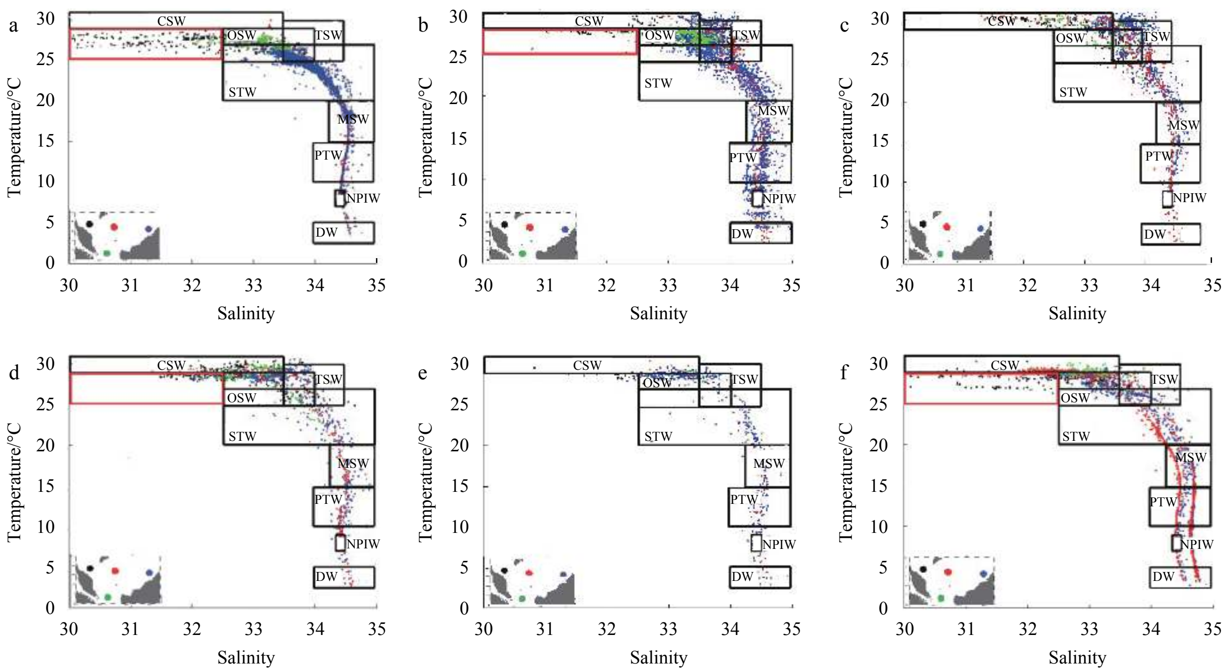

Fig. 11. T-S scatter plot (water mass) for peak northeast monsoon (a), weakening northeast monsoon (b), generating southwest monsoon (c), peak southwest monsoon (d), weakening southwest monsoon (e), and generating northeast monsoon (f). The location is marked with the color dot. The red box represents the new definition of CSW water mass. Each color represents the particular study area. Black represents GoT, Green Karimata Strai, Blue Sabah waters, and Red centre SSCS.

overcast skies and heavy rainfall during the northeast monsoon season (Roseli and Akhir, 2014; Yanagi et al., 2002). Overcast skies might reduce the low sun penetration and lowering the sea surface temperature. Heavy rainfall increases the river discharge into the GoT, resulting in fresher water mass in northeast monsoon compared to the southwest monsoon. Our results well-represented that varying monsoons characteristics with high river discharge are significant in the area like GoT.

Karimata Strait is located between SSCS and Java sea which the depth less than 500 m. Its location might influence the water intrusion between both seas especially during southwest monsoon period (Kok et al., 2015). According to Figs 11a and b, water mass in the Karimata Strait highly accumulate inside OSW and TSW range. However, in southwest monsoon period (Figs 11c and d) present the spreading of water mass in the Karimata Strait. The temperature and salinity range became larger (20–27°C, 32–34). This condition caused the water mass in Karimata Strait disperse more to another range which is inside STW during this period. Approaching the northeast period (Fig. 11f), the range become smaller again.

Both Sabah water and centre SSCS present almost similar water mass throughout the seasons. The location is exposed to the northern SCS and Sulu Sea. During peak season of northeast monsoon period (Fig. 11a), it shows the strong well mixed water mass properties. Afterward, the dispersion of water-mass occurs along the weakening phase of northeast monsoon (Figs 11b and c) which caused by the weakening of southwesterly wind speed. In addition, intrusion of water mass inside TSW obviously occurs which influence by water temperature rising. It was due to the decreasing of precipitation rate and strong penetration of sunlight. The location of Sabah water and centre SSCS can be influenced by water intrusion from Sulu Sea and northern SCS. The decreasing of water temperature started during weakening southwest monsoon (Figs 11e and f). Hence, it shows the water mass variability in Sabah water and centre SSCS is highly influenced by the northeast monsoon and slightly differ with Karimata and GoT waters.

Hence, both peak northeast and southwest monsoon shows the well-mixed water mass properties. But, peak northeast monsoon present strong separation of water mass among the locations compare to peak southwest monsoon. This is because of the weak wind speed during southwest monsoon compare to northeast monsoon. Hence, the mixing of water from Java Sea through the Karimata Strait which typically warmer than in SSCS can occurs. Well-mixed properties become weakers between TSW, OSW and STW range and obvious during weakening northeast monsoon. This is because of the decreasing of precipitation rate and cloud covers. Hence, at open water especially faced the direct penetration of sunlight and caused the water temperature increase. Besides, evaporation process occur and increased the water salinity. This situation prominent in transitional period of northeast-southwest monsoon. During transitional period of southwest-northeast monsoon, water temperature and salinity tend to be lower.

4 Conclusions

Study of water characteristics in SSCS was done by using the data from WOD. WOD datasets are very reliable in propagating the average features based on the seasonal variability. Data from WOD provide us the availability of datasets in study area for spatial and temporal study. However, certain location distribute the high compactness of datasets throughout the season. In this case, lack of datasets can be seen at the Karimata Strait, and Sabah-Sarawak waters which the dynamical changes of water by seasonal variability actively happens there. Water temperature in study area for surface and deep water is getting warmer throughout the years. Major seasonality which is northeast and southwest monsoon affect the variations of water temperature and salinity in SSCS, which the temperature is typically cooler during peak northeast than southwest monsoon. Thermocline range in shallow water (GoT and Karimata) is smaller than in deep water (centre SSCS and Sabah water). Besides, deepest ILD happen during peak northeast and southwest monsoon. Water mass in SSCS consists of 8 types, which the well mixed properties occurs during generating southwest monsoon. Temperature drop during northeast monsoon is identified in CSW. Location at the near shore area is likely to be influenced by freshwater discharge during peak monsoon seasons. At open sea, it more exposed directly by the cooler water from Vietnam. Study by using data from WOD is important and reliable due to high-resolution regional climatologies that reveal much greater understanding. Data from WOD give advantages in wide range of spatial and temporal for physical oceanographic studies. The availability of datasets allow us to track back the water temperature and water mass dynamics hence, probably can prove some important occurrence such as coastal upwelling. ENSO occurrence also is the exciting part of study about SSCS. Since datasets from WOD is long-temporal data, track back the datasets due to the ENSO history at previous years can be done to relate with the upwelling features at SSCS, next describe the fisheries product. However, the lack of other parameters such as nutrient and chlorophyll *a* data is something to ponder for future research. For the suggestion, all of datasets from oceanographic studies must be shared into this database. The effort from each country to collaborate into international program should be encouraged. Hence, the insufficient of datasets in particular area can be filled in.

Acknowledgements

Special thanks to the staff of Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu (UMT) for their contribution.

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