Sains Malaysiana 41(6)(2012): 701–714

Surface Circulation and Temperature Distribution of Southern South China Sea from Global Ocean Model (OCCAM)

(Peredaran Permukaan dan Taburan Suhu Selatan Laut China Selatan melalui Model Lautan Global (OCCAM))

MOHD FADZIL MOHD AKHIR*

ABSTRACT

The South China Sea (SCS) circulation in its southern region in the area between Peninsular Malaysia and East Malaysia was studied from the OCCAM (Ocean Circulation and Climate Advanced Modelling). This research aimed to illustrate the general overview of the seasonal surface current circulation and the surface temperature profile which are lacking in the region. The current along the Malaysia coast flows northward in the southwest monsoon and move in opposite direction in northeast monsoon with the maximum speed of 0.4 m/s and 1 m/s, respectively. While the current flows southward, the cooler water is transported into the region which reduces the temperature at the central of the basins nearly 3 °C. The study manages to analyse the importance of the monsoonal system on the region circulation and temperature distribution.

Keywords: Current circulation; ocean model; sea surface temperature; South China Sea

ABSTRAK

Peredaran arus di bahagian selatan Laut China Selatan (LCS) di antara Semenanjung Malaysia dan Malaysia Timur dikaji melalui OCCAM (Ocean Circulation and Climate Advanced Modelling). Kajian ini bertujuan untuk memberi gambaran secara umum peredaran arus permukaan dan suhu permukaan laut mengikut musin yang amat kurang difahami di kawasan ini. Arus di sepanjang pantai timur Semenanjung Malaysia bergerak menuju utara semasa musim monsun barat daya dengan kelajuan maksimum mencecah 0.4 m/s. Manakala semasa monsun timur laut arus menuju arah berlawanan iaitu ke arah selatan dengan kelajuan maksimum mencecah 1 m/s. Semasa arus bergerak menuju selatan, air bersuhu rendah dibawa dari bahagian utara yang menyebabkan bahagian tengah LCS mengalami penurunan suhu sebanyak 3 °C. Secara keseluruhan kajian ini mampu membuat analisis kepentingan monsun terhadap perubahan sistem melibatkan pergerakan arus dan perubahan suhu permukaan laut.

Kata kunci: Laut China Selatan; pemodelan laut; peredaran arus; suhu permukaan laut

INTRODUCTION

The Southern South China Sea (SSCS) is a semi-enclosed tropical continental shelf sea which mainly located between east and west of Malaysia. The region abides by the Vietnam coast to the north, Borneo to the south east and Indonesia to the south and includes Gulf of Thailand (Figure 1). It is basically the premise of shallow continental shelf of Sunda shelf which depth almost consistent at ~ 60 m. At north-east near Borneo, the continental shelf connects to the main SCS basins when depth increase rapidly up to 2000 m depth at the continental slope.

The SCS is subjected to the seasonal monsoon season (Dale 1956; Jianyu et al. 2000; Mao, Shi et al. 1999; Saadon & Camerlengo 1994; Shaw & Chao 1994; Tangang et al. 2011; Wyrtki 1961). The north-east monsoon dominates the SSCS region during November to March which results in strong northeasterly monsoon winds stress of nearly 0.3 N m-2 (Figure 2(b)). This strong monsoon wind causes a strong southwesterly current at east Malaysia coast. Meanwhile, the south-west monsoon dominates the SSCS region during April to August. Relatively weaker south westerly summer monsoon winds stress result in a wind stress of over 0.1 N m^{-2} that drives a northward coastal current off east Malaysia (Figure 2(a)).

Among the first studies around the region is conducted by the Hydrographic Office of the U.S. Navy. A number of surface current chart was produced before 1970's (Dale 1956; Wyrtki 1961). These results were mainly obtained from the ship drift and prevailing wind data. By analyzing these data, later Wyrtki (1961) pointed out that the entire system of SCS is under the influence of monsoon system. It is clear when he managed to illustrate certain current movement that move in opposite direction when the seasons of monsoon change. During the southwest monsoon, the circulation on the shelf is directed northward, while the northeast monsoon reverses the flowing direction (Figure 3).

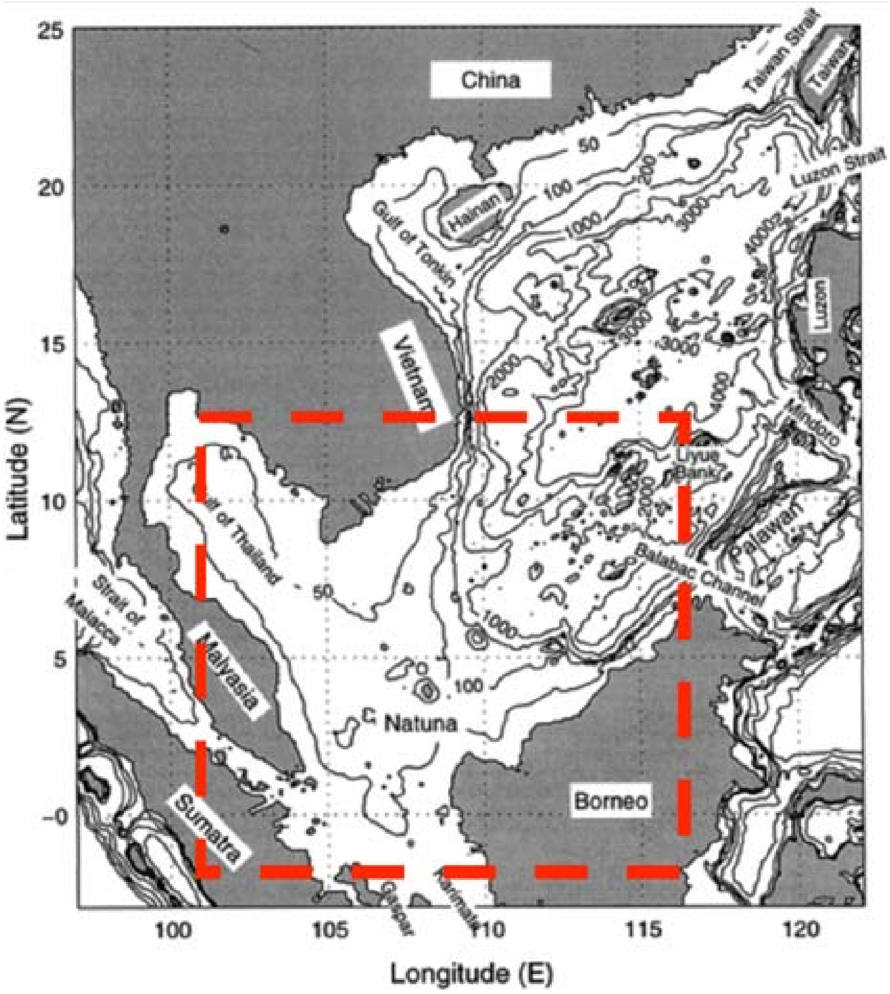


FIGURE 1. Bathymetry of the Sauth China Sea. Dotted line is the study area. Adapted from Chu et. al. (1999)

More intensive analysis was conducted to further support the earlier findings when (Xu et al. 1982) obtained the historical observational data during the year 1920-1970. The analysis of the data managed to demonstrate the seasonal pattern of current distribution which is consistent with the earlier findings. Nonetheless, with the extensive amount of data, much detailed observations are able to be resolved. Several eddies are pointed out within SCS in the study. With this new information, (Xu et al. 1982) concluded that the general SCS surface circulation is cylonic in winter but anticyclonic in summer. There is one dominant eddy in the SSCS which refers as Natuna eddy. It is located close to shelf break northeast of the continental shelf basin. In seasonal terms, the eddy has a different strength and size although its recirculation remains in the same place. That is the extent of the study which in general is still far from complete.

The distribution of sea surface temperature also changes with the monsoon. Winter monsoon (November-April) usually increases the cold water influx from the north into the region and consequently deepen the thermocline layer. Increase of surface water temperature for around 1°C and shallower thermocline is observed in the southwest monsoon (Camerlengo & Saadon 1994; Marghany et al. 1994). Although advection of cold water from the SCS basin circulation contribute to the temperature distribution change between the monsoon, effect of atmospheric influence also play a role. High precipitation and reduced heat influx from solar radiation because of overcast during the northeast monsoon also contribute to the sea surface temperature (Saadon & Camerlengo 1994).

There have been only a few studies involving the observational study of the SSCS circulation especially around Malaysian waters. Most of the extensive studies of SCS only cover the central deep basin (Chao et al. 1999; Chu et al. 1998; Chu et al. 1999; Mao, Shi et al. 1999; Shaw & Chao 1994; Shaw, Qu 2000; Xu, Qui et al. 1982). So far, studies in the southern region only manage to cover in the area less than 40 Nm from the coast (Saadon & Camerlengo 1994; Taira et al. 1996). Thus, it leaves a huge void area which is deemed to be explored. The earliest and yet the most comprehensive data so far is from Wyrtki (1961) which cover South China Sea from Indonesia up to Vietnam waters which include the entire part of Malaysia

a)

b)

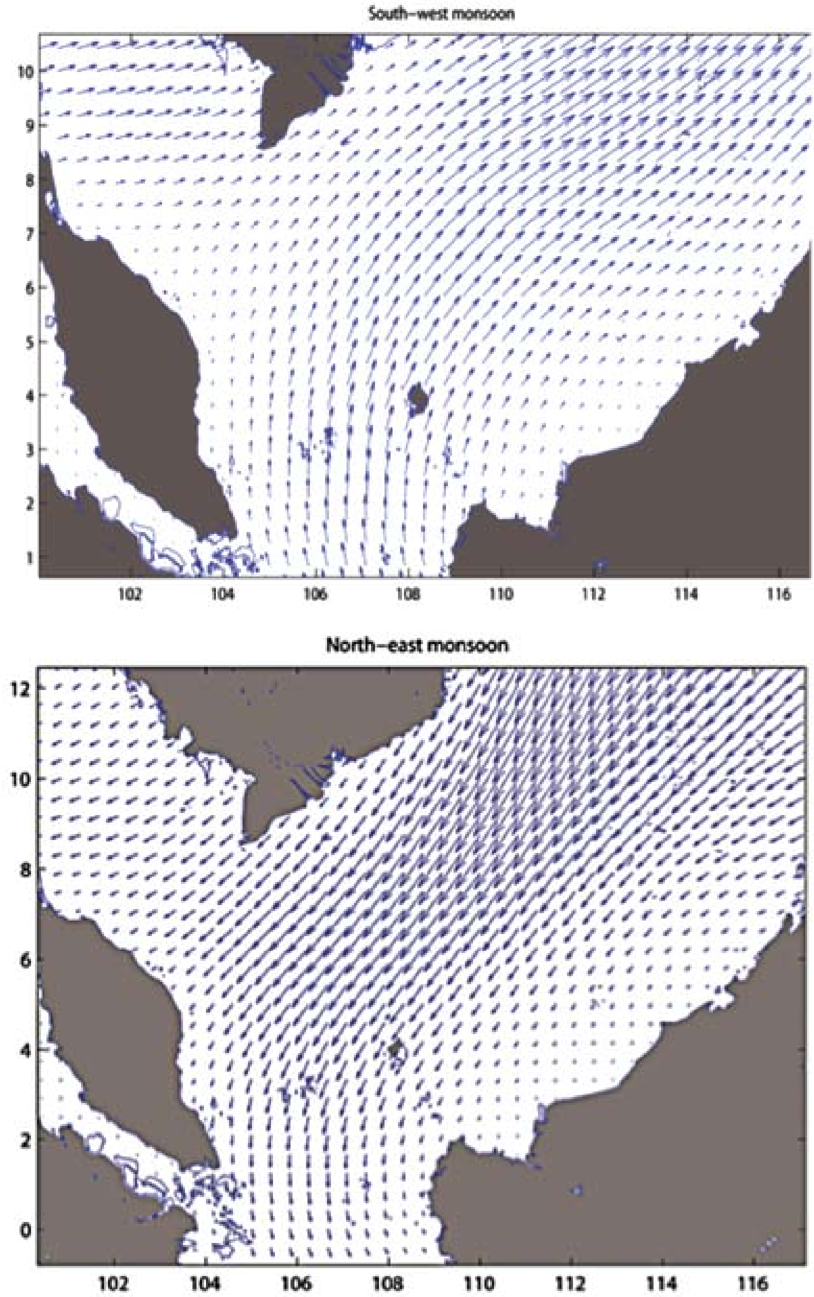


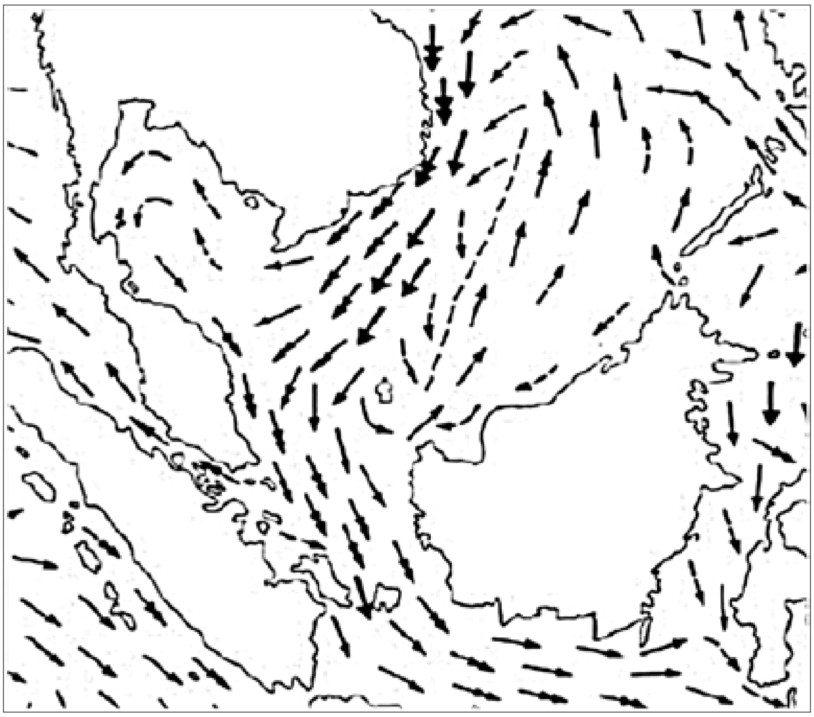
FIGURE 2. Wind stress from OCCAM for (a) South west monsoon and (b) Northeast monsoon

waters. Hence, lack of offshore current measurement has lead to the low amount of data which means, more research will be able to contribute to the enhancement of knowledge to this area.

In a much specific region, few researches were conducted in the area within the coast of Terengganu starting in 1980s. These data managed to demonstrate valuable information of the region physical characteristic (Saadon & Camerlengo 1994) analyzed the temperature data and found that during the northeast monsoon, the surface temperature is slightly lower with a difference of almost 1 °C to the southwest monsoon. From the physical profile, the study also suggested that the water mass characteristic in northeast monsoon has lower salinity and temperature comparatively. The changes in surface water profile are shared by earlier studies within the region of east coast of Peninsular Malaysia (Morgan & Valencia 1983; Lim & Tuen 1991; Taira et al. 1996)

During northeast monsoon, previous study suggested that precipitation and overcast skies are among the factors that contribute to lower temperature and salinity. Nonetheless, strong advection from northern region which distribute cool water with the southward flowing current into southern region is believed to be the main reason. While most of these factors were absent during southwest monsoon, evaporation activity create higher surface temperature at the study region.

a)



b)

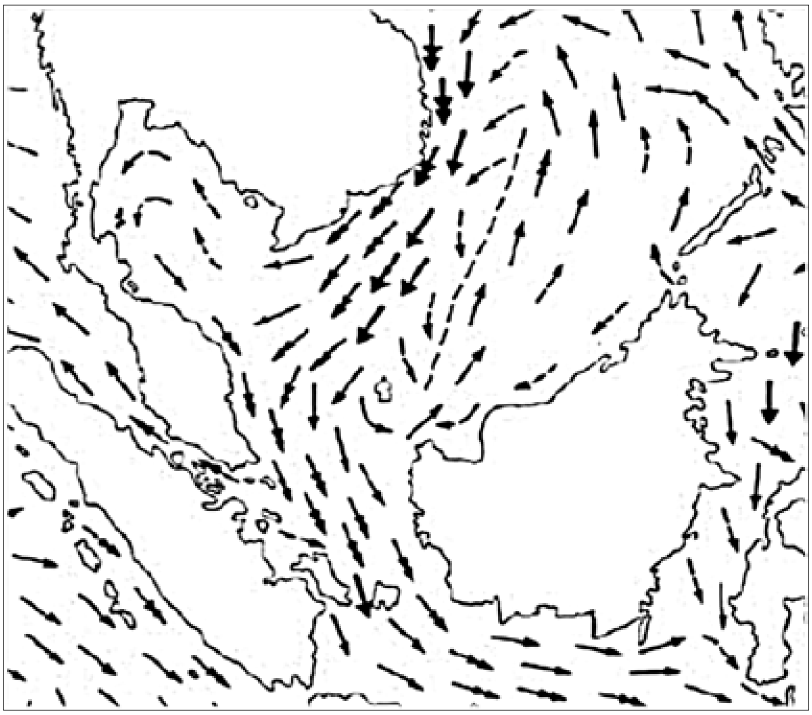


FIGURE 3. Observational surface circulation. a) Southwest monsoon and b) Northeast monsoon (Wyrtki, 1961)

By integrating the information available so far, it shows that the region dynamics is not really well understood. In terms of circulation system, the studies available so far concentrate more in the northern part of the study region, which leave a large void in the southern continental shelf basins. On the other hand, a number of research available close to the coast of Peninsular Malaysia has not be able to illustrate the bigger scale of surface characteristics in this region which is being studied.

This study will try to evaluate the OCCAM models, and demonstrate the result from the physical perspectives. Surface circulation of one year run, inclusive both monsoon seasons will be analyzed. Surface temperature distribution will also be examined, to describe the distribution changes throughout the year. The main objective of the study was to illustrate the general overview of the surface current circulation in the study region and the surface temperature profile by taking into account the seasonal shift. Nevertheless, it is important to stress the term used throughout this paper to avoid any misunderstanding. The terms of SSCS (southern South China Sea) is being referred to the study region as define in Figure 1, while SCS (South China Sea) is the entire section of the sea covering from China to the north and Malaysia to the south with the main basin located in the middle of the deep SCS basin (~ 15°N).

Method

Study of the southern SCS basin through global ocean model (OCCAM) has never been conducted before. This study tries to emulate the earlier study conducted by (Saunders Coward et al. 1999) which used OCCAM results as a tool in observing the circulation of the Pacific Ocean. This studies which aim to provide information about the circulation in data sparse regions managed to illustrate the ability of the model to produce results consistent with the field observation. This study tried to share the similar aim with the earlier, however one of the important aspects lacking in this study is field data observation. Direct comparison of model and field data will be minimal. Nonetheless, this will be a base study which will provide a general overview of the current circulation and surface water characteristic. In addition, the result of this model could also show some circulation features not previously known or only previously hypothesized.

The result of OCCAM within the study domain will be analyzed for two main parameters; temperature and current. In this study, surface current and circulation, and sea surface temperature were the main discussion points. The simulation result of 2003 will be used throughout the analysis to represent a whole year circulation. The only reason 2003 is chosen to be represented in this study is because the year is neutral from ENSO (El-Nino/La-Nina) activity. The result will be compared to satellite images in the same month and year of the earlier analysis. Coast of east Malaysia circulation features will be one of the important extract from this study.

The study incorporated seasonal changes into the analysis. With current circulation changes in opposite direction between the two monsoons, the specific understanding of the current circulation effect by the monsoon is critical. Here, it is important to differentiate between the atmospheric and oceanographic strength of the monsoon. In this study, only strength attributed to oceanography will be in use, unless stated.

Occam

The model is known as OCCAM (Ocean Circulation and Climate Advanced Modelling project). The project is directed by D. Webb, and details of its formulation are described by (Webb et al. 1997; Webb et al. 1998)). The model has 36 levels in the vertical, with thickness 20 m at the surface increasing to 250 m at depth, a spatial resolution of 1/4° everywhere, and a baroclinic time step of 15 min. The model has realistic topography (consistent with its spatial resolution, though limited to 5500 m in depth) and has channel dynamics for the Bering Strait. Surface wind forcing is provided by stress vectors interpolated from an annual cycle of 12 monthly fields: these are derived from European Centre for Medium-Range Weather Forecasts (ECMWF) winds for the years 1986–1988. The initialization of the potential temperature and salinity field were from the Levitus'94 annual mean climatology, and for the first 4 years of integration, values were relaxed to the annual mean with a time constant of 360 days; after this period, relaxation was switched off.

An exception to this statement must be made for the surface values, which are relaxed to interpolated daily values with a time constant of 30 days at all stages of the integration. The daily values were constructed smoothly from the seasonal Levitus values and had mean values equal to the Levitus monthly means (Kilworth 1996).

OCCAM is one of the most comprehensive global ocean model with highest resolution available for scientific community. The input data used for generating mechanism such as bathymetry and wind were using most reliable datasets available. For instance, European Centre for Medium-Range Weather Forecasts (ECMWF) is one of the most reliable wind stress data available for modeling at the time (Alpert et al. 1990; Josey et al. 2002). Temperature and salinity was forced with Levitus (1994) global ocean annual mean temperature and salinity field, which is one of the most dependable datasets for modeling work. Thus, OCCAM would be consistent for the specific purpose of analyzing regional scale basin circulation. To verify the constancy of the model, the next chapter will validate the model result with previous studies.

Model Validation

A number of modelling analysis have been studied in the area of South China Sea basins. Thus, comparison study wasl first be conducted to validate the reliability of OCCAM model in simulating SCS circulation. SCS circulation carried out by Chu et al. (1999) was the main reference for the comparison, especially on the circulation of mesoscale variance. Nonetheless, other important features especially on the well studied are of the northern region will be discussed with regards to the number of previous well documented study.

For comparison, circulation for the month of September and December was selected. The main reason was because during these months the current circulation of SCS basins provides significant speed representing the maximum development of southwest monsoon (summer) and northeast monsoon (winter) accordingly. During September (southwest monsoon) the inflow agrees with Chu et al. (1999) when the surface circulation generally follows suits with anticyclonicity in the southern basin (Figure 4). The model also clearly showed the inflow from Karimata Straits in the south and the outflow through Taiwan Straits in the North and eastern Luzon straits. Strong current along the Vietnam coast (western boundary current) also presents (Figure 5). Chu et al.

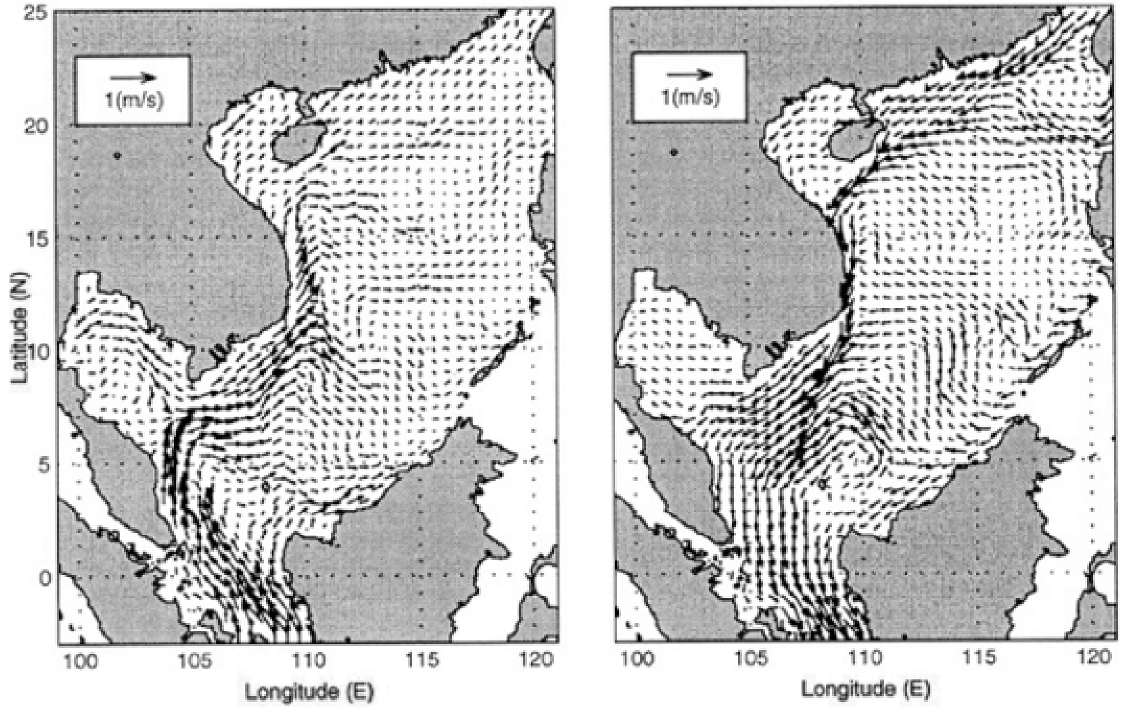


FIGURE 4. Mean surface circulation from Chu et. al. (1999) model run during (a) summer and (b) winter

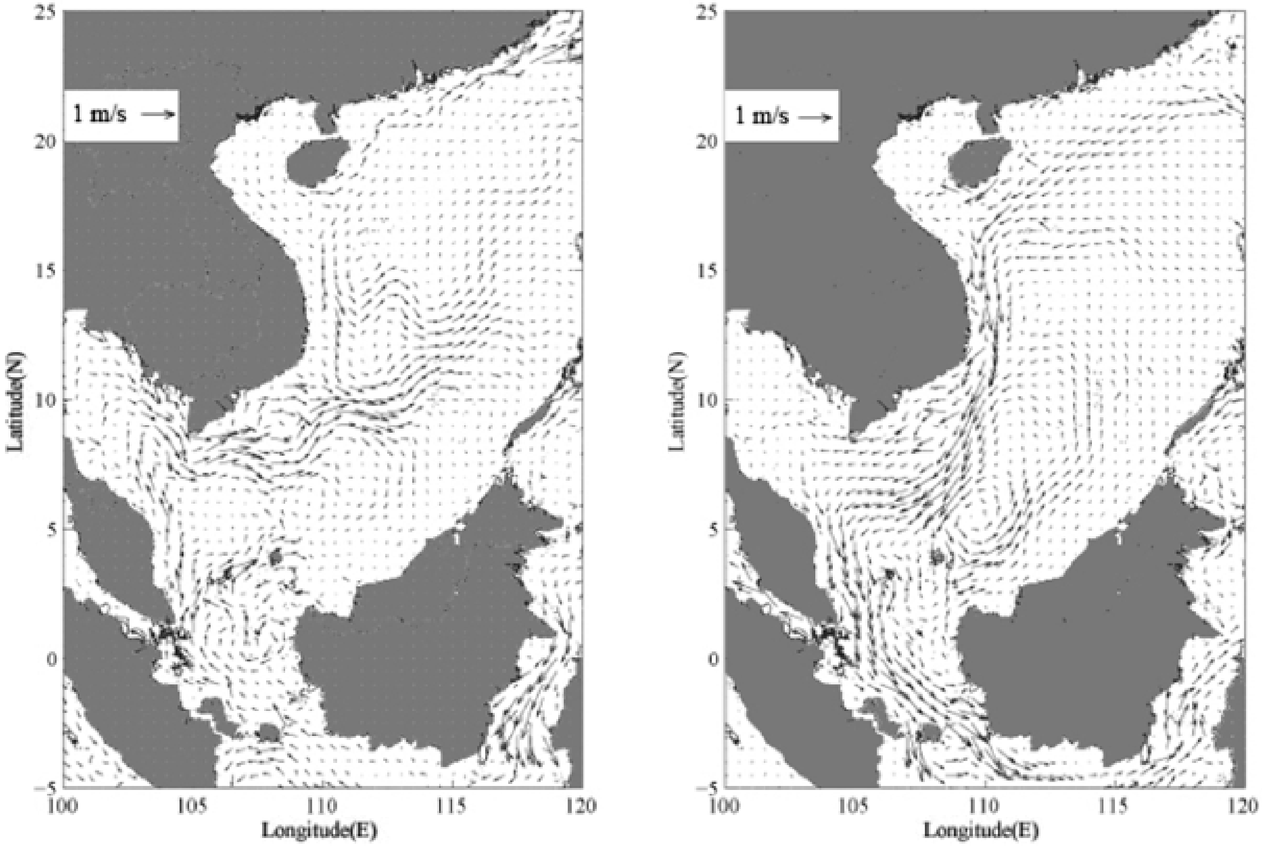


FIGURE 5. Mean surface circulation from OCCAM model during a) southwest monsoon dan b) northeast monsoon

(1999) suggested that the western boundary current splits into two at 12ºN. OCCAM model show similarity although it happen slightly south at 10ºN.

During northeast monsoon the current intensifies starting from Taiwan coast (20ºN), and flows south along the Vietnam coast. The flow spreads and become wider as it leaves Vietnam coast and approaching Peninsular Malaysia. Again this is also similar to what simulated earlier by Chu et al. (1999). The presence of anticyclonic Natuna Eddy was also documented from the model which located at 5 ºN, same for both model (Figure 4(b) and 5(b).

Previous studies also demonstrated important eddies present during both monsoon seasons. Xu et. al. (1982) pointed out the presence of cylonic eddy in the southern SCS during winter. With almost the same size and position with the model data, the eddy is actually Natuna Eddy that we referred earlier. In summer, small cyclonic eddy off Vietnam coast was clearly demonstrated by the model. Both eddies feature in the subsequent monsoon seasons agree with what was found by Xu et. al. (1982) through hydrographical data. These eddies presence was later confirmed by (Zhou et al. 1995) who use (Levitus 1982) climatological data set to diagnose annual and seasonal surface elevation of the SCS.

Throughout the model, the circulation within the southern SCS area was clearly distinguishable compared to SCS central basins. Meanders flows which can be observed along the strong current was one of the distinct differences of the model results from previous model (Chu et al. 1999) which showed smoother flow. Nonetheless, this meanders do not alter the main circulation. The only explanation for the meanders presence in the model result was because the vorticity equation used in OCCAM model. By utilizing the complete depth-integrated vorticity equation it was found that bottom pressure torques balance the advection of planetary vorticity in both surface and bottom (Saunders et. al. 1999).

Data Analysis

SURFACE CIRCULATION

Surface current within the South China Sea of Malaysia basins is characterized by the wind system of the monsoon season. From early hydrographic sea level and ship drift data, Wyrtki (1961) found a distinct seasonal feature of surface circulation within the basin. It has apparent current system leaning close to the Malaysia peninsular, and this current moves northward in summer and southward in winter. The later is particularly much stronger. This feature is almost similar with the coastal jet off the coast of Vietnam which reverses with the monsoon.

The OCCAM model data managed to illustrate the surface circulation within the study region. The analysis will focus at 4 specific months which start with May, August, September, and December. May and September is the transition month, where the model suggested a very minimal dynamics on the surface. On the other hand, August and December illustrate a highest current speed to better represent the northeast and southwest monsoon influence. Accordingly, the sequence of the analysis represent the cycle for a year which start with transitional time between from northeast to southwest monsoon in May.

Southwest monsoon circulation

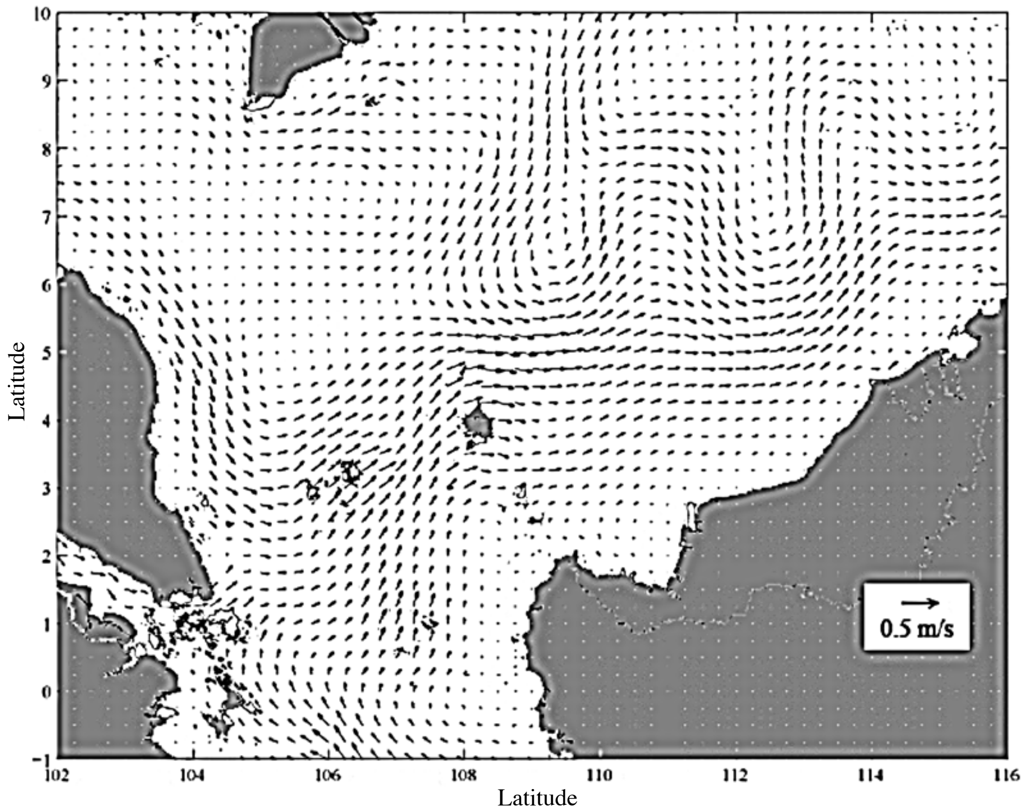
During the southwest monsoon period (May to August), the wind blew from southwest and the SCS circulation generally follow suit. The inflow was from Karimata Straits in the south (Chu, et al. 1999). May is the month of transition period between the northeast and southwest monsoon system. Figure 6(a) shows that during this month, the southwest current from Karimata Starits has started to develop. Nonetheless, the coastal current off peninsular Malaysia flowing southward in SCS basins is still observed.

Interestingly, this is a new findings where the coastal current is relatively strong even the current near south of Vietnam already start to overturn its direction by this time. The convergence between the southward flowing current at the Malaysia coast and northward flow current from Karimata can clearly be seen around 2°N off Malaysia coast. Chu et al. (1999) provide a complete modeling study of one year circulation over the whole SCS, and the results in May shows almost similar feature. Northward flows along the peninsular Malaysia coast redirected eastward near 5°N. This new information is illuminating and this showed the current along coast of peninsula Malaysia seems to have its own dynamics and not depending solely on the momentum of Vietnam Jets from the north.

In August, south-west monsoon system dominates the region when current flows from the south in the SCS, with the strongest current flowing at the western side of the basins (Figure 6(b)). The current which flows through Karimata Straits now flows northward freely because by this time, coastal current along Malaysia has changed direction and propagate northward. The current reach a maximum speed of ~ 0.3 m/s off the coast of Terengganu. The current flowed into the Gulf of Thailand, before it joined another coastal current within the gulf which then flow towards the southern tip of Vietnam. Here the current then moved eastward and is part of Nansha Western Coastal Current (Jianyu et al. 2000).

As shown in Figure 6 (a) and (b), it can be concluded that the general SCS surface circulation is cyclonic during post northeast monsoon and anticyclonic during southwest monsoon. The southwest monsoon anticyclonic system can be observe at the North-east of Natuna Island. The mesoscale size eddy which is known as Natuna eddy is a dominant feature within the study region and consistent throughout the season (Chu et al. 1998; Jianyu et al. 2000). The flow of the eddy was relatively strong on the northern part while the southern part was weak. This is mainly due to the strong current on the north which meanders with the eddy.

a)



b)

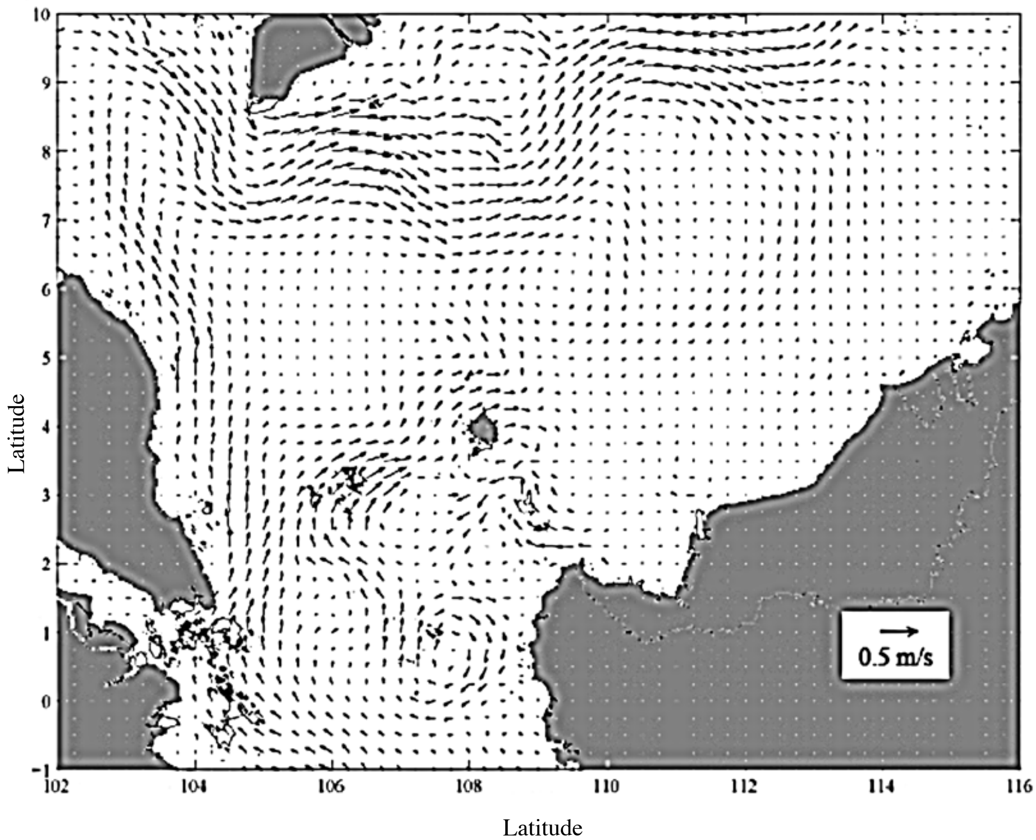


FIGURE 6. Surface circulation monthly average from OCCAM. (a) May and (b) August

Northeast Monsoon

During northeast monsoon, the wind stress changes dramatically to the opposite direction. The current circulation change has also caused the current direction to change. During October, the surface circulation was relatively weak (Figure 7 (a)). This transition characteristic is different to what found earlier in the month of May which was rather active.

As the northeast monsoon circulation takes place, the current circulation turn into reverse direction as expected. The main current lie close to the Malaysia peninsular now moves southward. This is consistent with the wind stress curl of North-east monsoon which takes place starting from November. In winter, the current flowing southward is stronger and wider. Originate from the Vietnam Jet, the current split into 2 near 5°N (Figure 7 (b)). This splits is observed when the current approach Natuna Island where the current one flowing eastward into the Natuna Eddy and another heading westward into the western side of the basin. Interestingly, from the results, it can be seen that the Vietnam jet leaves the Vietnam coast in much wider profile. The current turn direction and move toward the Malaysia peninsular in a form of broad band current between 5°- 9°N. The current then squeeze into thinner band of current and reach its maximum at the southern tip of the peninsular, flowing into southern Sumatera and continue into the Karimata Starits.

The current flowing along the Malaysia Peninsular was also analyzed to demonstrate the clear picture of current distribution along the Malaysia coast. At the southern part of Malaysia east coast between the coast and a group of island at 106°E longitude, the current appear to intensify. Figure 8 shows the transect profile of the current flowing off the east coast at latitude of 2°N. In south-west monsoon season, the current profile along the transect line shows the current lean towards the coast with the north-south component speed of 0.4 m/s. In the northeast monsoon, strong current which move southward shows a higher velocity. Reaching 1 m/s, the current was broader than what observed in southwest monsoon. This is related to the different strength of current produce by both seasons. Thus, this area have shown that before leaving/ upon entering the south china sea basin the current lean toward the Malaysia east coast and the strongest current lie off the 2 ° N latitude between 104.5 -106° E.

The model observation framework describe above provides a general overview of surface circulation explaining about the process and features of the SCS upper layer circulation in response to the season during northeast and southwest monsoon. However, the transition period which lies around May is slightly complicated and need further explanation. Interestingly, both transition periods (May and October) share different characteristics. It was likely that the weaker southwest monsoon wind stress faded earlier and inconsequently has less impact on the circulation.

Current off Peninsular Malaysia

The presence of a band of current off Peninsular Malaysia was further analyzed in this study to show the intensity of the current which flow according to the monsoon system as explained above. In both monsoon seasons, the current lean against the Peninsular Malaysia, but the profile; width and velocity varies through the season.

In the southwest monsoon, Figure 8(a) and (b) shows the North-South (N-S) component of the current velocity at the cross transect off Terengganu (5.8°N) and Johore coast (2°N). The N-S component velocity is 0.4 m/s in both transects. The maximum section of the current width was also similar, but the maximum flow in Terengganu was slightly away from the coast. In northeast monsoon, the N-S component velocity in Terengganu is lower than in Johore with 0.7 m/s and 1.0 m/s accordingly. Both current flow close to the coast with the current width in Johore slightly bigger.

The presence of such current has been observed by Dale (1956) and Wyrtki (1961) but the significance was never been discussed. Similar to the wind stress, the current also shows that it is much stronger in northeast monsoon. The current is obviously wind driven, but other factor such as geopotential gradient could also contribute to the current strength.

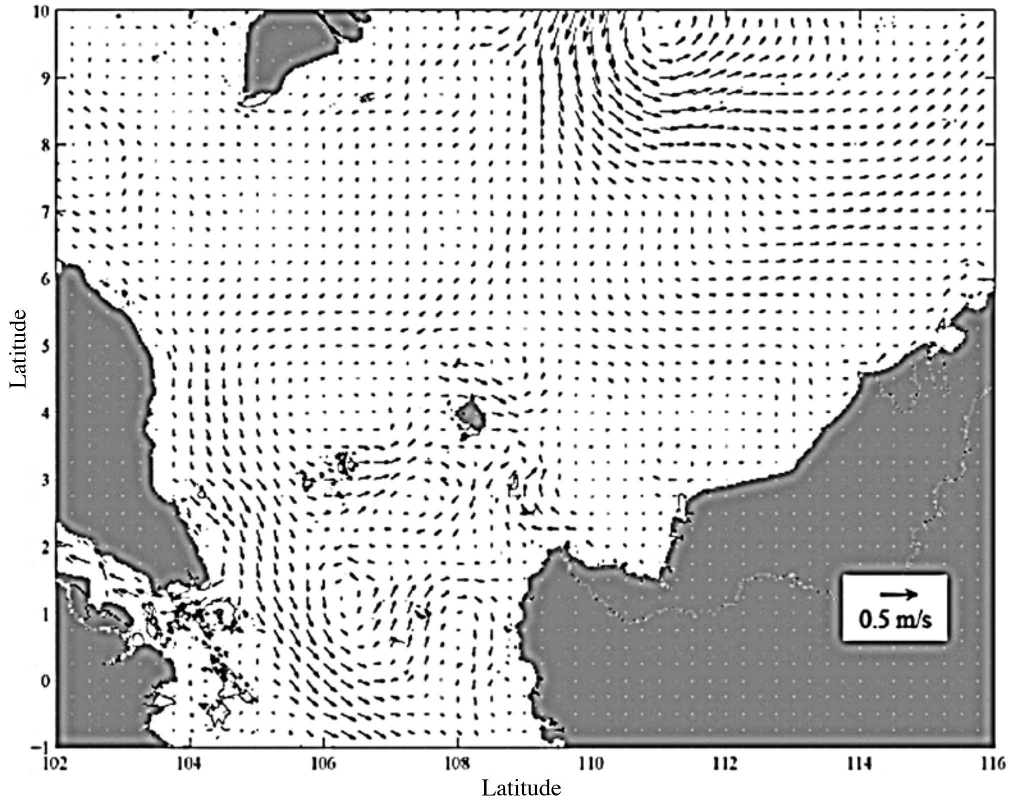
Sea Surface Temperature Distribution

Based on satellite data, Liu et al. (2001) asserted that the southward western boundary current of SCS increase its intensity as it flows south along the south Vietnam coast in winter. Generated in the north, the flow continues southward along the continental shelf breaks (called the Sunda Slope) which bring pronounce cold tongue waters into the continental shelf as a result of advection. This can clearly be seen from Figure 9(a), which demonstrates December sea surface temperature monthly average which represent northeast monsoon.

The cold tongue is distinct on the shelf break and start to spread as it reach around into the continental shelf around 8 °N.The cold tongue is about 25 °C, while in the middle of the SCS continental basin the surface temperature is 26 °C. Then it formed into a circular shape which was believed to be influenced by the Natuna Eddy which was dominant in that area. Meanwhile, at the southern tip of Vietnam, we can see there was another tongue of cold water which was relatively small flows toward the Gulf of Thailand. This showed how the cold tongue split at the southern Vietnam. These was consistent with current circulation which we showed earlier where the current split into two at the south of Vietnam, where the main current flows along the shelf break and continue into the continental shelf while the smaller current heading west.

During the south-west monsoon season, central SSCS seas surface temperature was about 3 °C higher (Figure 9 a)) than during northeast monsoon. By this time, the

a)



b)

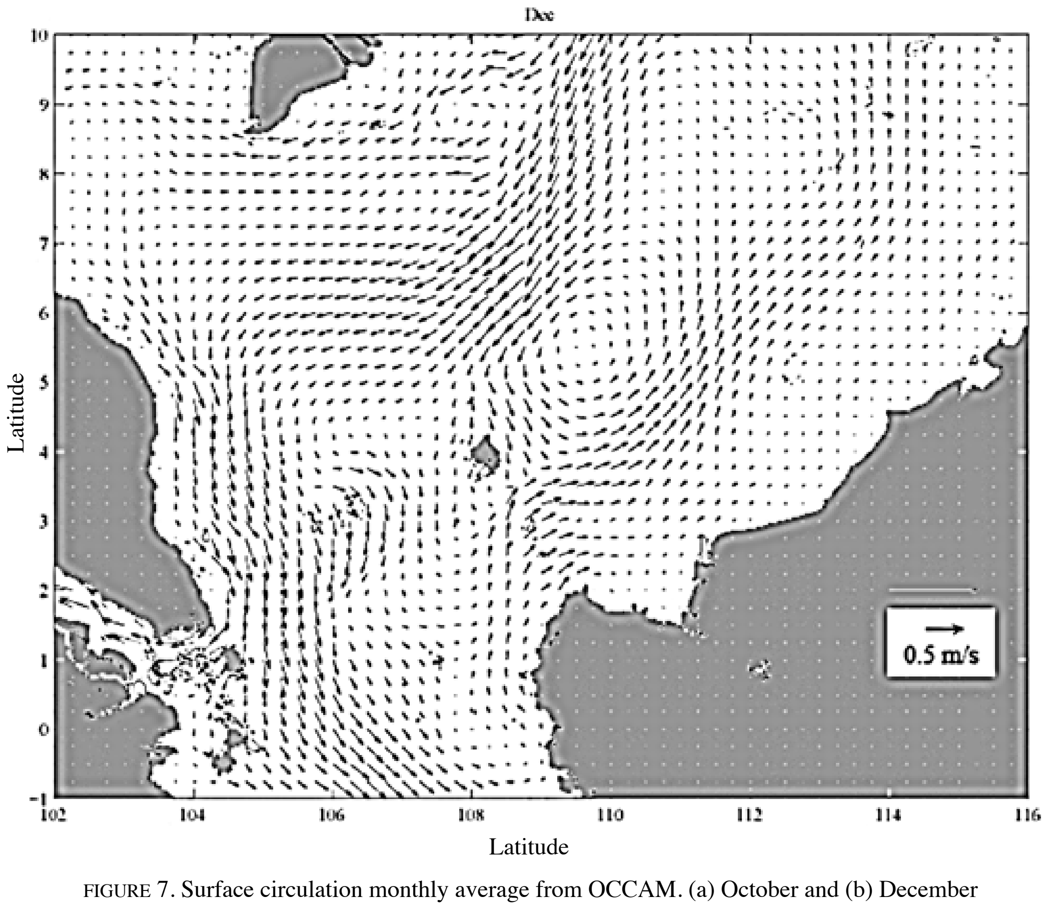


FIGURE 7. Surface circulation monthly average from OCCAM. (a) October and (b) December

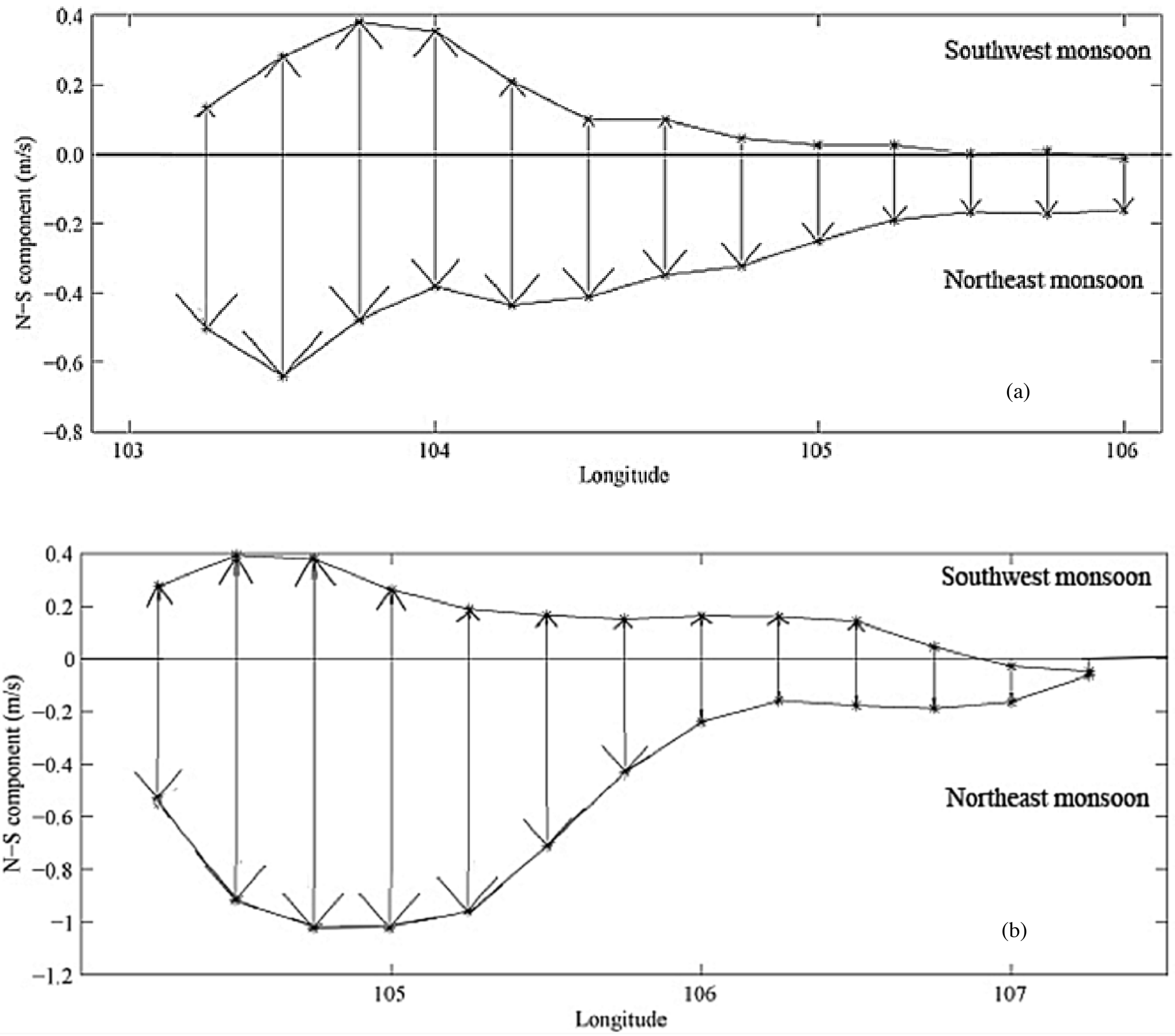


FIGURE 8. N-S component surface velicity component as cross transect (a) Terengganu coast (5.8°N) and (b) Johore coast (2°N)

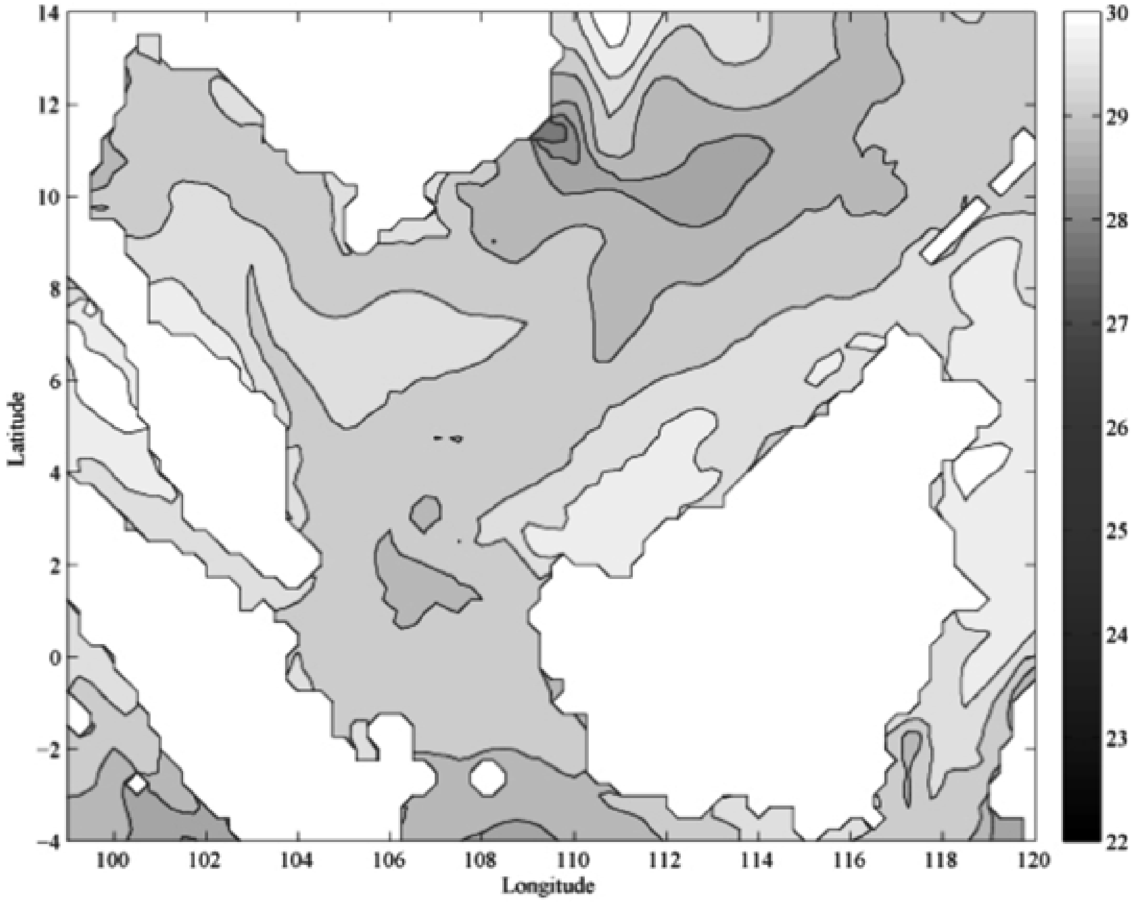
current flowing northward brings tropical waters from Indonesia. Higher temperature water was then spread through the central area of the SSCS. Area close to the Borneo coast and offshore Terengganu coast (7°N) however is slightly warmer. Figure 7(a) shows that in this season the circulation is relatively low in these areas, thus mixing on the surface of the ocean is depleted.

CONCLUSION

The SSCS circulation and the sea surface temperature were analyzed using OCCAM results. During the southwest (June-September) monsoon period, the SSCS circulation is northward. With the main current flows against the coast of peninsular Malaysia. The current flow reaches 0.3 m/s along the coast which starts from Karimata Straits and continue to the north into Gulf of Thailand before heading towards Vietnam coast. The important feature highlighted in this study was the circulation in the month of May where the current pattern in the south and north differ and converge at 2°N. This finding is new to the region but nothing conclusive can be made from this model. On the other hand, earlier model such as Chu et al. (1999) also showed the sudden change in direction as the northward flow approaching 5ºN. The convergence happens further north than what found by OCCAM, nonetheless both features are almost the same. Transition period between the two monsoon seasons is believed to be the perfect timing for such feature. The northeast monsoon circulation is stronger and last longer than southwest monsoon circulation. While the southwest monsoon current starts to develop, the earlier system is fading but still present because of momentum. By August, the southwest surface current is already dominant. The dynamics of this feature is still unknown, but it is interesting for future research.

The presence of coastal current of Peninsular Malaysia was clear from the surface circulation and velocity analysis. The current flows close to the coast and identical to the

a)



b)

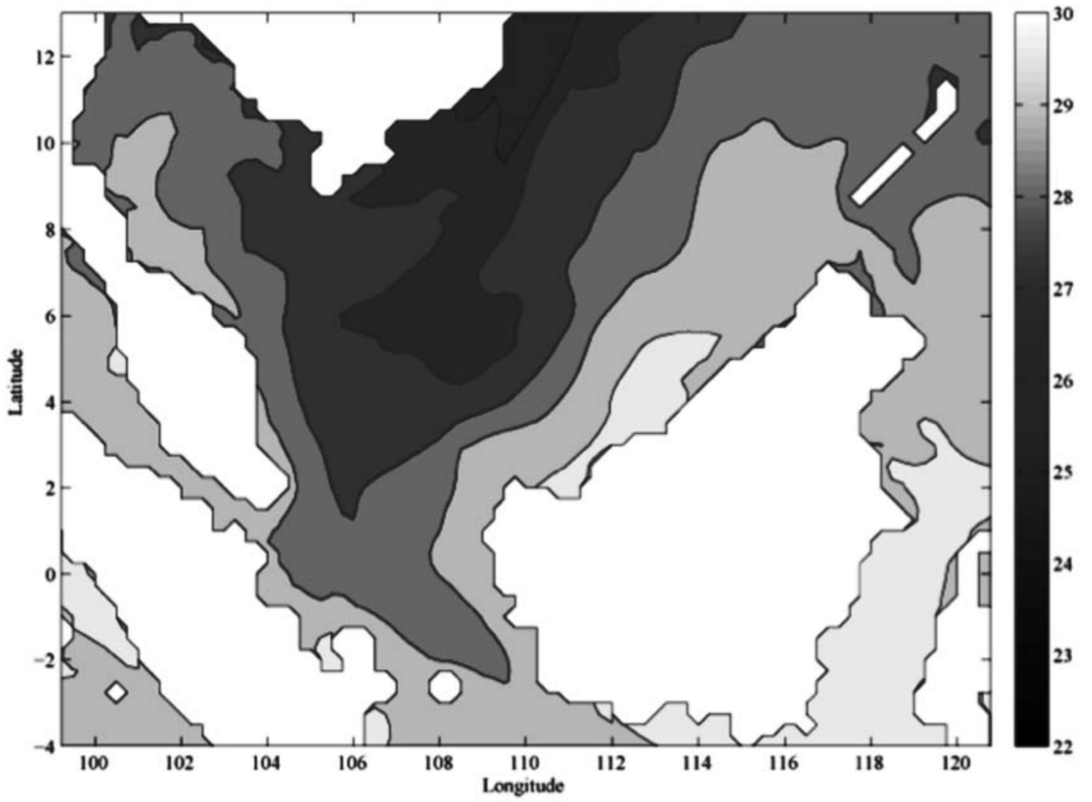


FIGURE 9. Sea surface temperature (SST) monthly average from OCCAM (in degree °C). a) August and b) December.

whole system which accord to the monsoonal variation. This study only managed to show the presence of the current without any specific detail. It is much valuable in the future to look into the depth of integrated profile of the current and its evolution throughout the year to further understand the system.

Sea surface temperature within the region also varies through the season. Advection of cold water from the north has influence the SST in the region. The presence of cold tongue is pronounced in the middle of SSCS, where the water is originate from the north. This is consistent with earlier findings (Lim & Tuen 1991; Marghany et al. 1994; Saadon & Camerlengo 1994). Such feature has caused the SSCS continental shelf basins surface temperature lowers as much as ~3 °C from the state of southwest monsoon. Although northeast monsoon create a pool of cool basins, close to the shore the temperature only drop merely 1 °C. This can be seen along the coast of peninsular Malaysia. Nonetheless, along Borneo coast, the SST shows very minimal changes. Low circulation has lead to low mixing within the region and the SST almost consistent between the seasons.

In conclusion, it is worth to mention that the study through global ocean model is experimental per se. The lack amount of field research in the region has made the comparison between model result and field observation minimal. Low understanding of the current system and SST distribution for the area also has made this research serve as a base study. In general, the overall result provided by the OCCAM model is a useful overview analysis neither to prove nor to summarize the circulation of the region. It is just to provide a beneficial outline that can be brought into better perspective of the area where the field data observation is limited.

REFERENCES

Alpert, P., Neeman, B. U. & Shay-El, Y. 1990. Climatological analysis of Mediterranean cyclones using ECMWF data. *Tellus A* 42(1): 65-77.

Camerlengo, A. & Saadon, M. N. 1994. Dynamic behaviour of upper layers of the South China Sea. *National Conference on Climate Change, Universiti Putra Malaysia, Faculty of Science and Environmental Studies, UPM.*

Chu, P.C., Chen, Y. & Lu, S. 1998. Wind-driven South China Sea deep basin warm-core/cool-core eddies. *Journal of Oceanography* 54: 347-360.

Chu, P. C., Edmons, N. L. & Fan C. 1999 Dynamical mechanisms for the South China Sea seasonal circulation and thermohaline variabilities. *Journal of Oceanography* 29(11): 2971-2989.

Dale, W. L. 1956. Wind and drift currents in the South China Sea. *The Malaysian Journal of Tropical Geography*. 8: 1-31.

Jianyu, H., Kawamura, H. Hong, H. & Qi, Y. 2000. A review on the currents in the South China Sea: Seasonal circulation, South China Sea warm current and Kuroshio Intrusion. *Journal of Oceanography* 55: 607-624.

Josey, S.A., Kent, E.C. & Taylor, P.K 2002. Wind Stress forcing of the ocean in the SOC climatology: Comparisons with the NCEP–NCAR, ECMWF, UWM/COADS, and Hellerman and Rosenstein Datasets. *Journal of Physical Oceanography* 32(7): 1993-2019.

Kilworth, P.D. 1996. Time interpolation of forcing fields in ocean models. *J. Phys. Oceanogr.* 27(6): 136-143.

Levitus, S. 1982. Climatological. Atlas of The World Ocean.

Lim, J. T. & Tuen, K.L. 1991. Sea surface temperature variations in the South China Sea during northern hemisphere winter monsoon. *Proceedings of the Second WESTPAC Symposium*.

Liu, Z.Y., Yang, H.J.& Liu, Q.Y. 2001. Regional dynamics of seasonal variability in South China Sea. *J. Phys. Oceanogr.* 31: 272-284.

Mao, Q. W., Shi P. & Qi, Y.Q. 1999. Sea surface dynamics topography of geostrophic current over the South China Sea from Geosat altimeter observation. *Acta Oceanologica* 21(1): 11-16 (in Chinese with English abstarct).

Marghany, M.M., Saadon, M. N., Hussain M. L & Mohamed, M. I. 1994. Seasonal thermohaline variation in coastal waters off Kuala Terengganu, Malaysia. *National Conference of Climate Change, Universiti Putra Malaysia, Faculty of Science and Environmental Studies, UPM.*

Morgan, J.R. & Valencia M.J. 1983. The natural environment setting. *Atlas for Marine Policy in Southeast Asia Seas*. California: University of California Press.

Qu, T. 2000. Upper-Layer Circulation in the South China Sea. *J. Phys. Oceanogr* 30: 1450 -1460.

Saadon, M. N. & Camerlengo, A. 1994. Interannual and seasonal variability of the mixed layer depth of the South China Sea. *National Conference on Climate Change, Universiti Putra Malaysia, Faculty of Science and Environmental Studies*, UPM.

Saunders, P. M., Coward A.C. & Cuevas B.A.D., 1999. Circulation of the Pacific Ocean seen in a global ocean model (OCCAM). *Journal of Geophysical Research* 104(C8): 18,281-218,299.

Shaw, P. & Chao, S. 1994. Surface circulation in the South China Sea. *Deep Sea Research Part I: Oceanographic Research* 41: 1663-1683.

Shaw, P. T., Chao S. Y. & Fu L.L., 1999. Sea surface height variations in the South China Sea from satellite altimetry. *Oceanologica Acta* 22(1): 1-17.

Taira, K., Saadon, M. N., Kitagawa, S. & Yanagi, T. 1996. Observation of temperature and velocity in the coastal water off Kuala Terengganu, Malaysia. *Journal of Oceanography* 52: 251-257.

Tangang, F., Xia, C., Qiao, F., Juneng, L. & Shan, F. 2011. Seasonal circulations in the Malay Peninsula Eastern Continental Shelf from a wave-tide-circulation coupled model. *Ocean Dynamics* 61(9): 1317-1328.

Webb, D.J., Coward A.C., Cuevas B.A.D. & Gwilliam C.S., 1997. A Multiprocessor Ocean General Circulation Model Using Message Passing. *Journal of Atmospheric and Oceanic Technology* 14(1): 175-183.

Webb, D. J., Cuevas, B. A.D. & Coward, A.C. 1998. The first main run of the OCCAM global ocean model. S. O. Centre.

Wyrtki, K. 1961. Physical oceanography of the Southeast Asian waters. *NAGA report,* vol. 2. La Jolla, California,

The University of California, Scripps Institution of Oceanography.
Xu, X. Z., Qui, Z. & Chen, H.C. 1982. The general description of the horizontal circulation in the South China Sea. *Proocedings of the 19 880 Symposiums on Hydrometeorology of the Chinese Society of Oceanology and Limnology,* Beijing, Science Press.
Zhou, F. X., Shen, J.J., Berestov, A.L. & Marushkevich, A.D. 1995. Seasonal features of large-scale geostrophic circulation in the South China Sea. *Tropical Oceanology* 14(4):9-14.

Jabatan Sains Marin
Fakulti Pengajian Maritim dan Sains Marin
Universiti Malaysia Terengganu
21030 Kuala Terengganu
Terengganu, Malaysia

Institut Oseanografi dan Sekitaran (INOS)
Universiti Malaysia Terengganu
21030 Kuala Terengganu, Terengganu
Malaysia

*Corresponding author; email: mfadzil@umt.edu.my

Received: 18 January 2010
Accepted: 5 January 2012