

Seasonal Variation of Surface Circulation Along Peninsular Malaysia' East Coast

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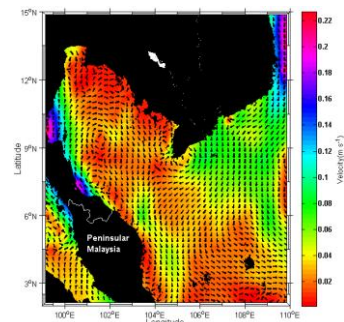
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Article history

Received :6 February 2014

Received in revised form :
24 July 2014

Accepted :9 October 2014



Abstract

The sea surface circulation pattern over the coast of Peninsular Malaysia's East Coast during Northeast Monsoon (NE) and Southwest Monsoon (SW) are derived using the seasonally averaged sea level anomaly (SLA) data from altimetric data and 1992-2002 Mean Dynamic Ocean Topography. This altimetric data has been derived from multi-mission satellite altimeter TOPEX, ERS-1, ERS-2, JASON-1, and ENVISAT for the period of nineteen years (1993 to 2011) using the Radar Altimeter Database System (RADS). The estimated sea level anomaly (SLA) have shown similarity in the pattern of sea level variations observed by four tide gauges. Overall, the sea surface circulations during the NE and SW monsoons shows opposite patterns, northward and southward respectively. During the SW monsoon, an anti-cyclonic circulation has been detected around the Terengganu coastal area centred at (about 5.5° N 103.5° E) and nearly consistent with previous study using numerical modelling. The estimated geostrophic current field from the altimeter is consistent with the trajectories of Argos-tracked Drifting Buoys provided by the Marine Environmental Data Services (MEDS) in Canada.

Keywords: Surface current circulation; Monsoon; RADS; Peninsular Malaysia; Satellite altimetry

Abstrak

Corak peredaran arus permukaan laut di sepanjang pantai timur pentas benua Semenanjung Malaysia semasa Monsun Timur Laut (TL) dan Monsun Barat Daya (BD) yang diperolehi menggunakan data purata paras laut dari data altimeter dan model 1992-2002 Mean Dynamic Ocean Topography. Data altimeter ini telah diperolehi daripada satelit altimetri pelbagai misi TOPEX, ERS -1, ERS -2, Jason -1, dan ENVISAT bagi tempoh sembilan belas tahun (1993-2011) dengan menggunakan Pangkalan Data Radar Altimeter (PDRA). Anggaran anomali paras laut (SLA) telah menunjukkan persamaan dalam corak perubahan paras laut seperti yang diukur dari empat stesen pasang surut. Secara keseluruhannya, peredaran permukaan laut semasa monsoon TL dan BD menunjukkan corak bertentangan, iaitu masing-masing ke arah utara dan selatan. Semasa Monsun BD, peredaran anti-siklon telah dikesan di sekitar kawasan pantai Terengganu berpusat di (kira-kira 5.5° N 103.5° E) dan hampir konsisten dengan kajian sebelum ini yang menggunakan model berangka. Anggaran arus geostrophik dari altimeter adalah konsisten dengan corak pergerakan boya Argos yang dibekalkan oleh Marine Environmental Data Services (MEDS) di Kanada.

Kata kunci: Peredaran arus permukaan; Monsun; PDRA; Semenanjung Malaysia; Satelit Altimetri

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1.0 INTRODUCTION

The eastern continental shelf of Peninsular Malaysia (MEPCS) is a part of the Sunda Shelf and located at the southern region of the South China Sea (SSCS). This region is shallower water region in the SCS where depth is less than 100m as shown in

Figure 1. MEPCS is connected with Java Sea and Indian Ocean through Karimatra Strait and Malacca Strait, respectively. The ocean circulation pattern in the region become the essential information to support the marine activities such as

commercial shipping, offshore oil operation and fisheries that have been growing rapidly and contributing significantly to the Malaysia's economy. Previous studies have pointed out that the seasonal ocean circulation of SCS is controlled predominantly by the seasonal monsoon season [1,2,3,4,5,6] with two main seasons driven the SCS circulation; the Northeast monsoon (NE) and the Southwest monsoon (SW).

Only limited number of studies which are focused the surface circulation of MPECS [e.g., 5,6,7,8,9,10,]. Most of previous studies have proved that surface currents of the SCS move in the opposite direction when the monsoon changes.

During SW monsoon and NE monsoon, the surface circulation is directed to southward and northward, respectively. Simulation of the MPECS circulation by [6] and [8] using wave–tide–circulation coupled model and Princeton Ocean Model (POM), respectively have revealed an anti-cyclonic eddy in MPECS region during SW Monsoon as shown in Figure 2. [11] and Idris and [12] have studied the sea surface circulation at the South China Sea using single mission satellite altimeter data. However, both studies which rely to single mission satellite altimetry not reveal the anti-cyclonic eddy in the MPECS.

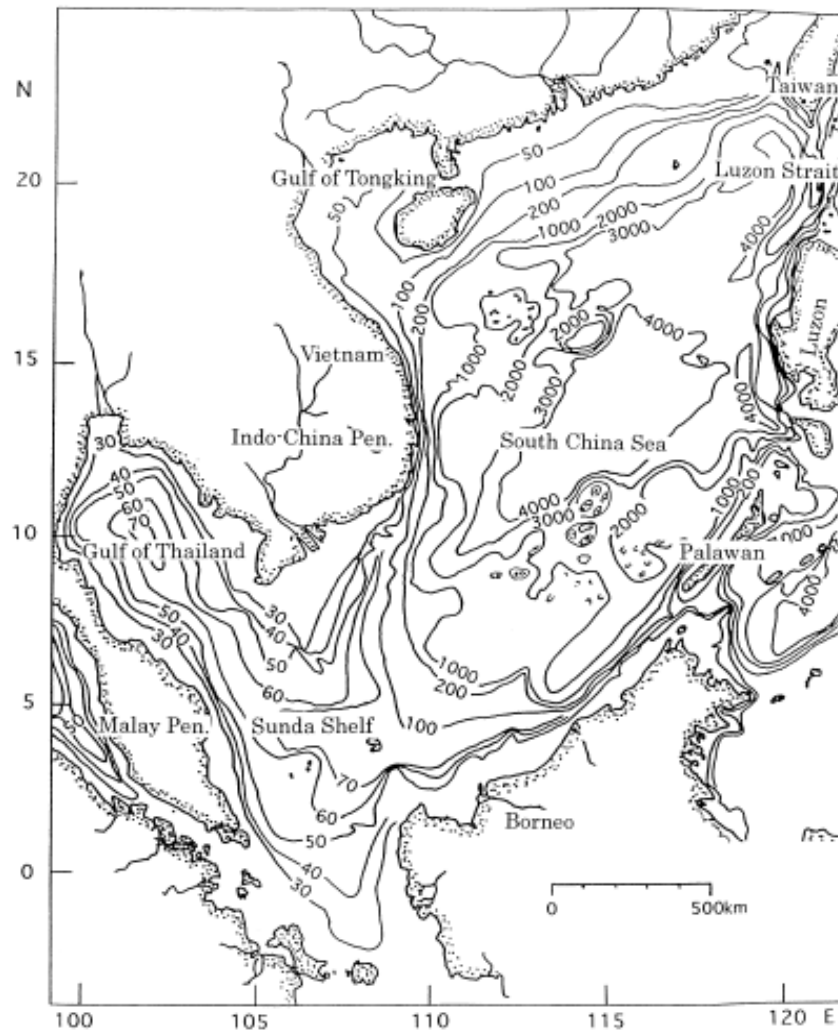


Figure 1 Bathymetry of the South China Sea [11]

Combination of multi-mission will gives an improved estimation of the mesoscale features of surface circulation compared to the results derived from only one altimeter [13,14]. Thus, the aim of this study to describe the seasonal variation of circulation pattern in the MPECS with use of altimetric data from multi mission-mission satellite altimetry (ERS1&2, TOPEX/POSEIDON, JASON 1&2, and ENVISAT). Nineteen years of multi-mission satellite altimetry data from 1993 to 2011

have been derived from the Radar Altimeter Database System (RADS) to estimate the surface current in the study area.

2.0 ALTIMETER DATA PROCESSING

The multi-mission satellite altimetry data for the period of January 1993 to June 2011 have been processed in the present study derived using Radar Altimeter Database System (RADS). It consists 10 years of TOPEX/POSEIDON, eight years of

JASON-1, three years of JASON-2, four years of ERS-1, 17 years of ERS-2 and nine years of ENVISAT observation. The sea surface height from altimetry data have been corrected for orbital altitude, altimeter range corrected for instrument, sea state bias, ionospheric delay, dry and wet tropospheric corrections, solid earth and ocean tides, ocean tide loading, pole tide, electromagnetic bias and inverse barometer correction. The summary of environmental corrections which applied in altimeter data processing is showed in the Table 1. In order to merge data from different satellite platforms, homogeneous and cross-calibrated sea are required. According to this, the reference frame biases between the different satellite missions that reflect the differences in the orbits are applied and as well

as some other geographical differences in the altimeter dependent models.

A so-called dual-crossover minimization analysis are performed in which the orbit of the TOPEX-class satellites fix as a reference and those of the ERS-class satellites are adjusted simultaneously. The area used for the crossover minimization is much larger than the study to have sufficient crossover information. Gaussian Weighting Functions (low pass filter) with sigma 0.5° has been applied to reduce the noise signal from SLA. Then ERS-class and TOPEX-class data were merged and gridded to sea level anomaly grids with block size 0.25°.

Table 1 Summary of environmental correction

Correction/Model	Editing (m)		Description
	Min	Max	
Orbit/ Gravity field			All satellites: EIGEN GL04C ERS: DGM-E04/D-PAF
Dry troposphere	-2.4	-2.1	All satellites: Atmospheric pressure grids
Wet troposphere	-0.6	0.0	All satellites: Radiometer measurement
Ionosphere	-0.4	0.04	All satellites: Smoothed dual-freq. ERS/POSEIDON: NIC08
Dynamic atmosphere	-1.0	1.0	All satellites: MOG2D
Ocean tide	-5.0	5.0	All satellites: GOT4.7
Load tide	-0.5	0.5	All satellites: GOT4.7
Solid earth tide	-1.0	1.0	Applied (Elastic response to tidal potential)
Pole tide	-0.1	0.1	Applied (Tide produced by Polar Wobble)
Sea state bias	-1.0	1.0	All satellites: CLS non parametric ERS/POSEIDON: BM3/BM4 parametric
Reference	-1.0	1.0	DNS08 mean sea surface
Engineering flag			Applied
Applied reference frame biases (cm)			JASON-1: -4.8, ERS-1: +3.4, ERS-2: +7.3, ENVISAT: +5.2 JASON-2:+15.9, POSEIDON:-1.5 TOPEX: Reference frame

3.0 ESTIMATION OF GEOSTROPHIC CURRENT

Assuming the geostrophic balance, the geostrophic current anomaly is computed from the multi-year average of 19 years (1993-2011) SLA using the following equation [15,16,17]:

$$u = \frac{-g\partial\zeta}{f\partial y} \quad v = \frac{g\partial\zeta}{f\partial x}$$

$$f = 2\Omega\sin(\varphi)$$

where ζ is the SLA, u and v are the east and north velocity components of sea surface geostrophic current, g is the local acceleration due to gravity, f is the Coriolis parameter with Ω

being the earth rotational rate (7.292115×10^{-5}), φ is the latitude, and x and y are the local rectangular coordinate.

In order to compute absolute geostrophic current, the mean currents obtained from the 1992-2002 Mean Dynamic Ocean Topography (Figure 2) are added to the geostrophic current anomaly velocities. This model has been developed using joint data of satellite altimetry, near-surface drifters, National Centers for Environmental Prediction (NCEP) wind and Gravity Recovery and Climate Experiment (GRACE) (Maximenko, 2009). The data can be downloaded at Asia-Pacific Data-Research Center website (<http://apdrc.soest.hawaii.edu/projects/DOT>). Details of 1992-2002 MDOT model are given in [18]. Since the geostrophic current equation is not valid near the equator where Coriolis force almost zero, the surface geostrophic current is not estimated within about 2° of the equator.

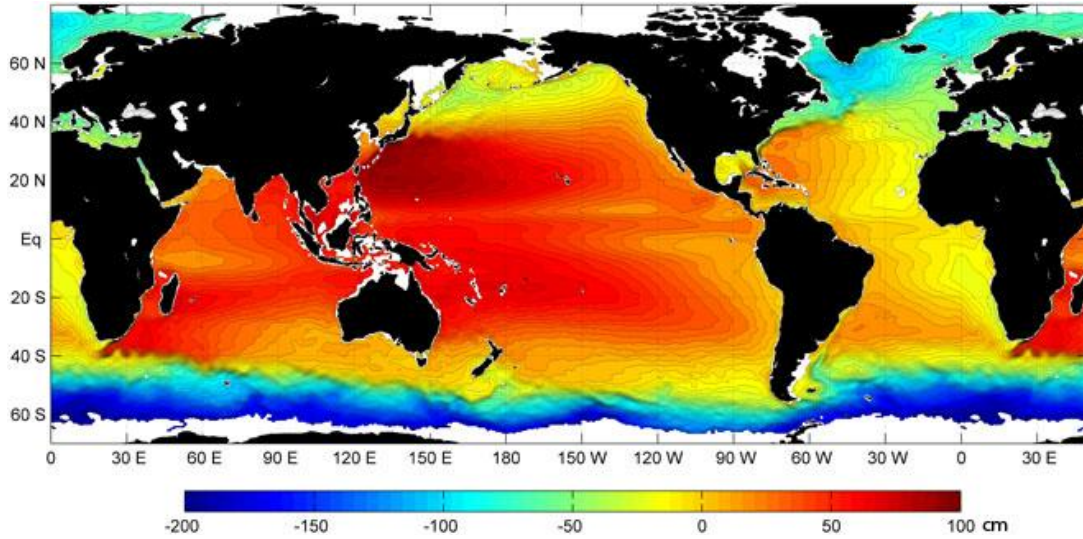


Figure 2 1992-2002 Mean Dynamic Ocean Topography by [18]

4.0 RESULTS AND DISCUSSION

In order to evaluate the estimated SLA from altimetric data, the result are compared with the monthly time series of four tide gauge along the east coast of Peninsular Malaysia. Meanwhile, the estimated geostrophic current are compared with the track of drifting buoys provided by Marine Environmental Data Services (MEDS) of Canada .

4.1 Comparison of SLA with tide gauge data

The selected tide gauge station; Cendering, Geting, Tanjung Gelang, Pulau Tioman, and Tanjung Sedili are provided by Jabatan Ukur & Pemetaan Malaysia (JUPEM) and the location of stations is shown in Figure 1. The monthly averages of SLA

are computed and interpolated onto the tide gauge position using Inverse Distance Weighting (IDW) method to compute the monthly time series of SLA. The result is shown in Figure 3. Based on the result, the variation pattern of sea level between tide gauge and altimeter, present a quite uniform pattern and indicate good agreement between tide gauge and altimetry data.

4.2 Seasonal variations of surface circulation pattern

Geostrophic currents are computed from the long term averaged SLA (1993-2011) and plotted based on the monsoon season. Here, each season are defined as NE Monsoon from December to January and SW Monsoon from June to September, in terms of variations of the monsoon

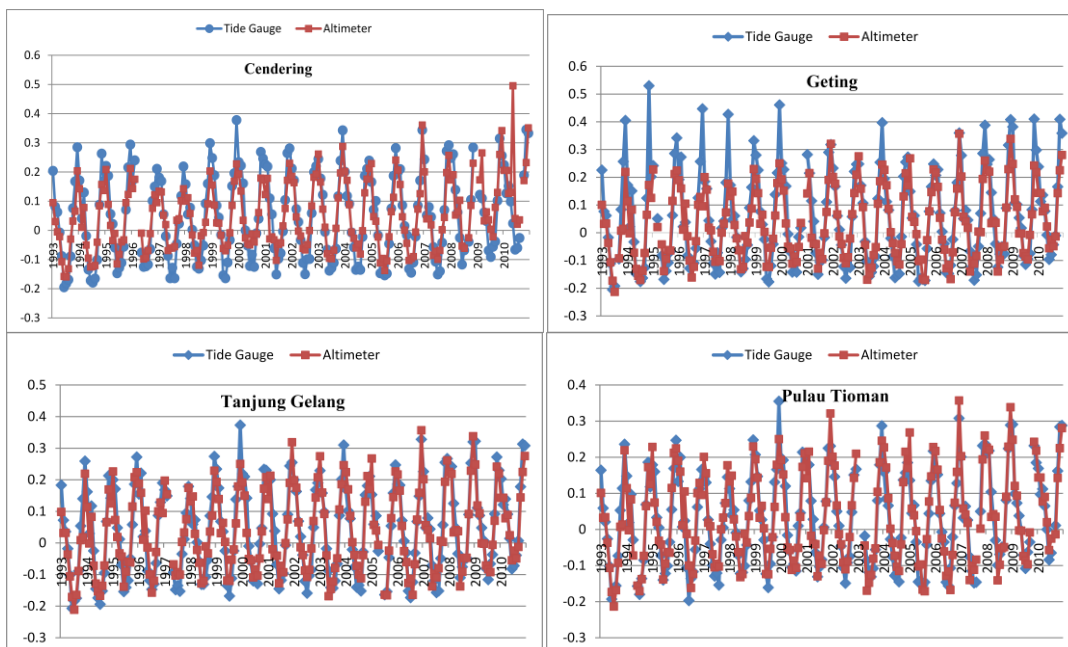


Figure 3 Plot of monthly sea level variation from (a) Cendering (b) Geting (c) Tanjung Gelang (d) Pulau Tioman tide gauge station

NE Monsoon

Figure 4 shows the composite plots of average absolute geostrophic current for NE Monsoon superimposed on the geostrophic current velocity. During the NE monsoon winds blow from the northeast and surface current known as Vietnam Coastal Current (VCC; [19]) flows southward along the coast of Vietnam. After leaving the coast of Vietnam, the VCC can be seen splitting into two branches over the Sunda Shelf (4°N-6°N), one flowing eastward approaching Natuna and Borneo Islands. Another branch continues to flow along the Peninsular Malaysia towards Karimatan Strait. In order to verify the current

pattern during NE Monsoon, the result have been compared with drifter trajectories. Table 2 list the elected drifter's information and the trajectories of drifter is shown in Figure 5. It can be seen that the current pattern during NE Monsoon closely consistent to track of drifter 22513, 22571 and 22572.

All the drifter were released during the NE Monsoon moved all the way along the coast of Vietnam before turn to southward at near 6°N-7.5°N and flowing along the east of Peninsular Malaysia. The trajectories of these drifter have confirmed the VCC and circulation pattern along east of Peninsular Malaysia during NE Monsoon.

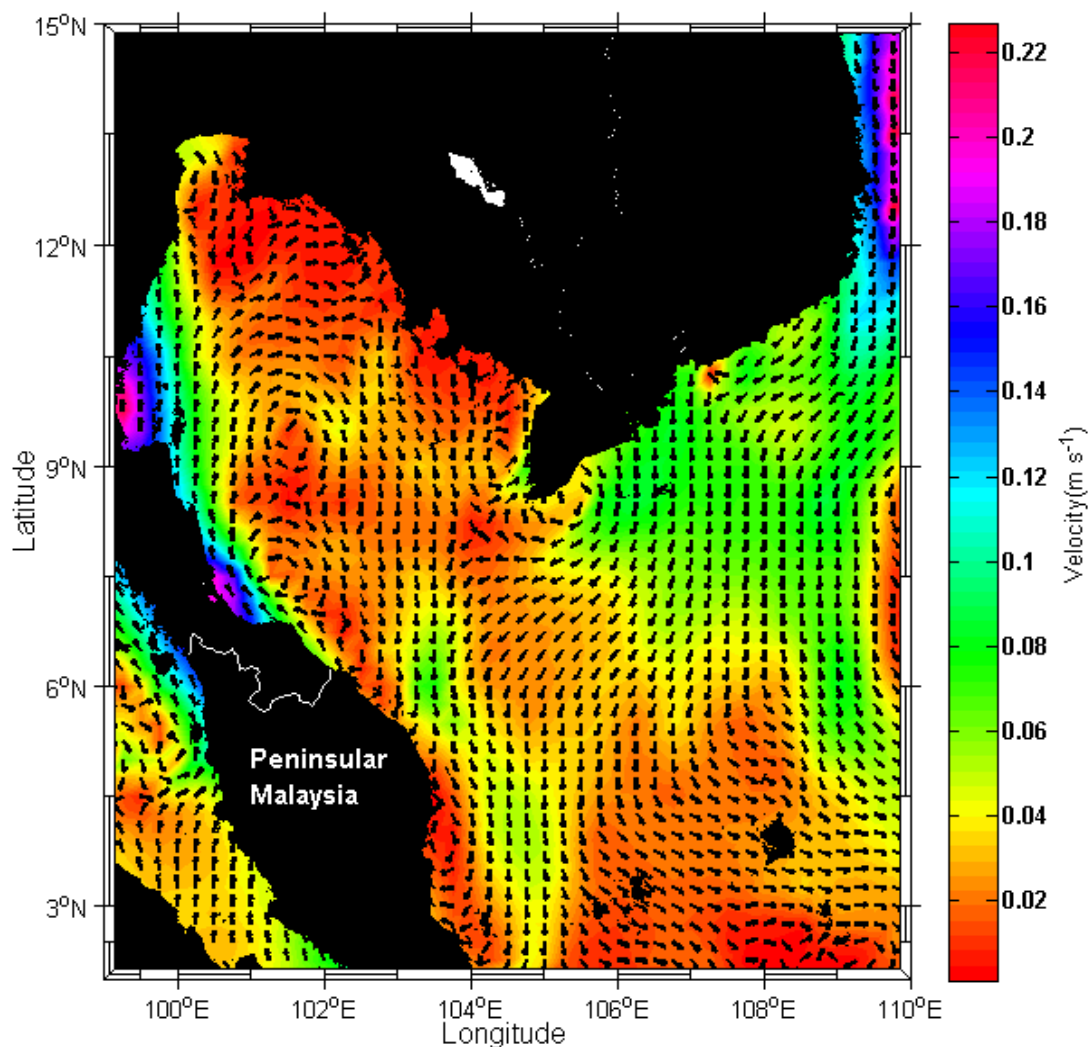


Figure 4 Averaged geostrophic current for nineteen years during NE Monsoon.

At around 6°N, part of the southward flowing current turns cyclonically to northward before entering the Gulf of Thailand (GOT) and flowing northward along the west coast of GOT. The changes in the direction are probably due to the geometry of the

coastal area which is blocked part of the southward current to flow along the Peninsular Malaysia east coast. Interestingly, the surface current pattern have confirmed by the drifter 22587 as shown in Figure 5.

Table 2 Drifting buoys information

Drifter ID	Start			End		
	Date	Lat ($^{\circ}$ N)	Long ($^{\circ}$ E)	Date	Lat ($^{\circ}$ N)	Long ($^{\circ}$ E)
22513	1995/09/21	14.448	111.995	1995/12/17	0.055	108.497
22571	2004/11/29	17.129	109.553	2005/02/02	1.176	104.459
22572	2003/12/20	17.06	110.003	2004/02/26	0.011	105.736
22587	2003/12/20	17.145	109.971	2004/03/03	13.209	99.976

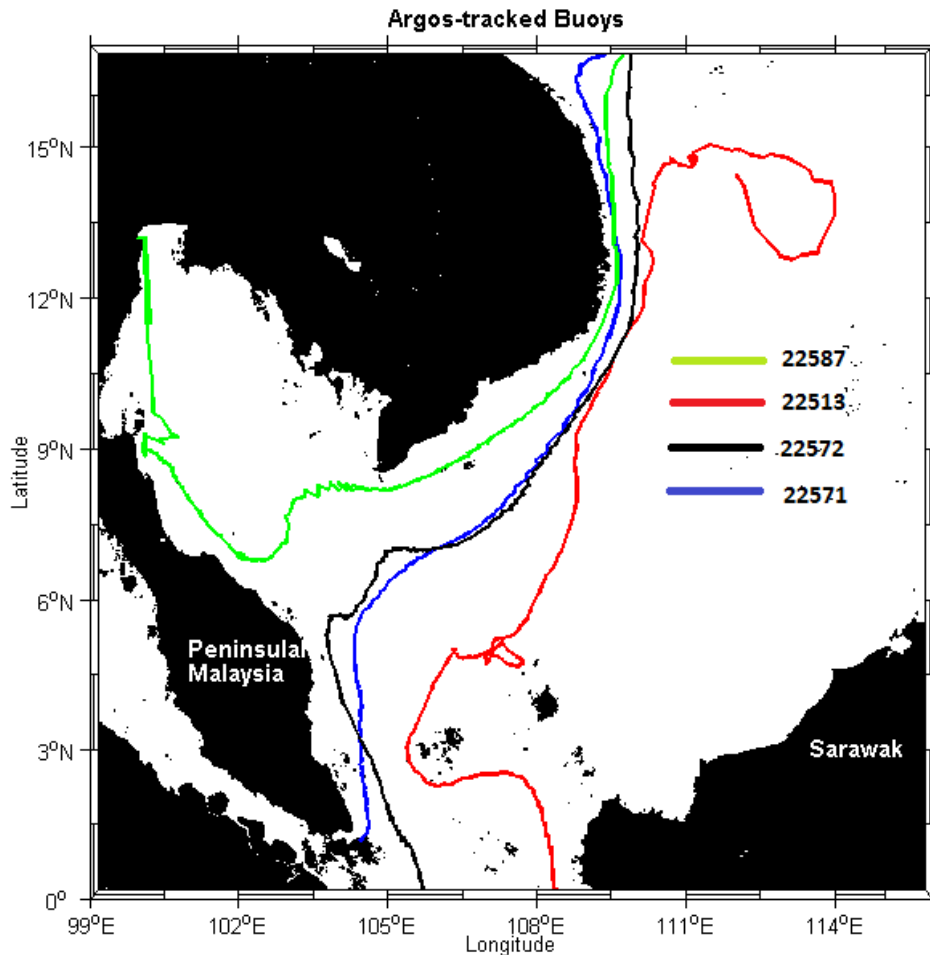


Figure 5 Trajectories of Argos-tracked drifter in the Vietnam and Peninsular coastal area

SW Monsoon

During SW Monsoon, the features of circulation in the SCS almost the opposite direction to that seen during NE Monsoon as shown in Figure 6. The circulation pattern in the MPECS during SW Monsoon is rather complex than during NE Monsoon. The pattern shows MPECS current is flowing southward. The interesting feature to discuss here is the existence of an anti-cyclonic eddy centered at (about 5.5° N 103.5° E) near the east coast of Peninsular Malaysia nearly consistent to what has been reported by [6] and [8]. The surface current in the southern part east coast of Peninsular Malaysia

flow north-westward towards coastal area after influenced by the eddy system and continues flowing along east coast of Peninsula Malaysia before turning direction to north-eastward (about 6° N- 7° N) and flowing along the southeast of Vietnam coastal area. The current continues flowing along the southeast of Vietnam coastal area. The current continues flowing along the southeast of Vietnam coastal area and leaves the Vietnam coast at near 9.5° N- 13° N after converging with southward current around 10.5° N. [2] have called this current as southeast Vietnam offshore current (SEVOC). An anti-cyclonic eddy also has formed in the east coast of Vietnam and north of Natuna Island.

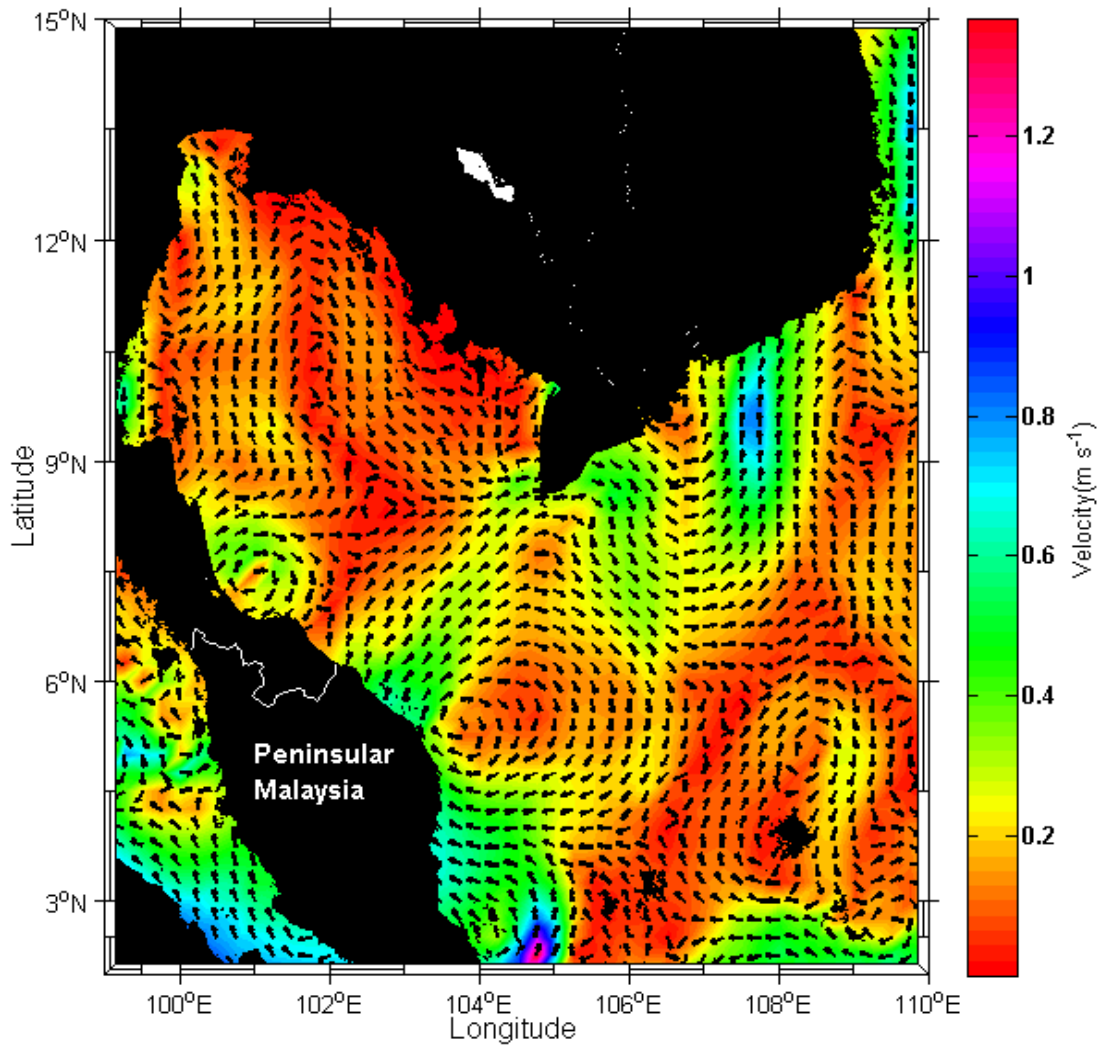


Figure 6 Averaged geostrophic current for nineteen years during SW Monsoon.

4.3 Anti-cyclonic eddy in the MPECS during SW monsoon

The geostrophic current in the Malaysian region is analyzed in detail to demonstrate the formation of anti-cyclonic eddy near the east coast of Peninsular Malaysia. Figure 7 and Figure 8 show the climatology of monthly geostrophic current. During NE Monsoon, December, January and February, the current pattern is almost the same. Originating from the Vietnam Jet, the current is flowing southward along the east coast of Peninsular Malaysia. In March, the current still flow southward along the east coast of Peninsular Malaysia. However in April

and May, the current begins to flow cyclonically southward and the anti-cyclonic eddy forms near the coastal area in May. In June, the anti-cyclonic eddy is well developed and prevails through July until September. During second inter-monsoon, the anti-cyclonic eddy that formed in SW Monsoon season still exists up to October, but has weakened and in November, the eddy disappears. In November and December, NE Monsoon wind begins to influence the current pattern where, the current change direction to southward.

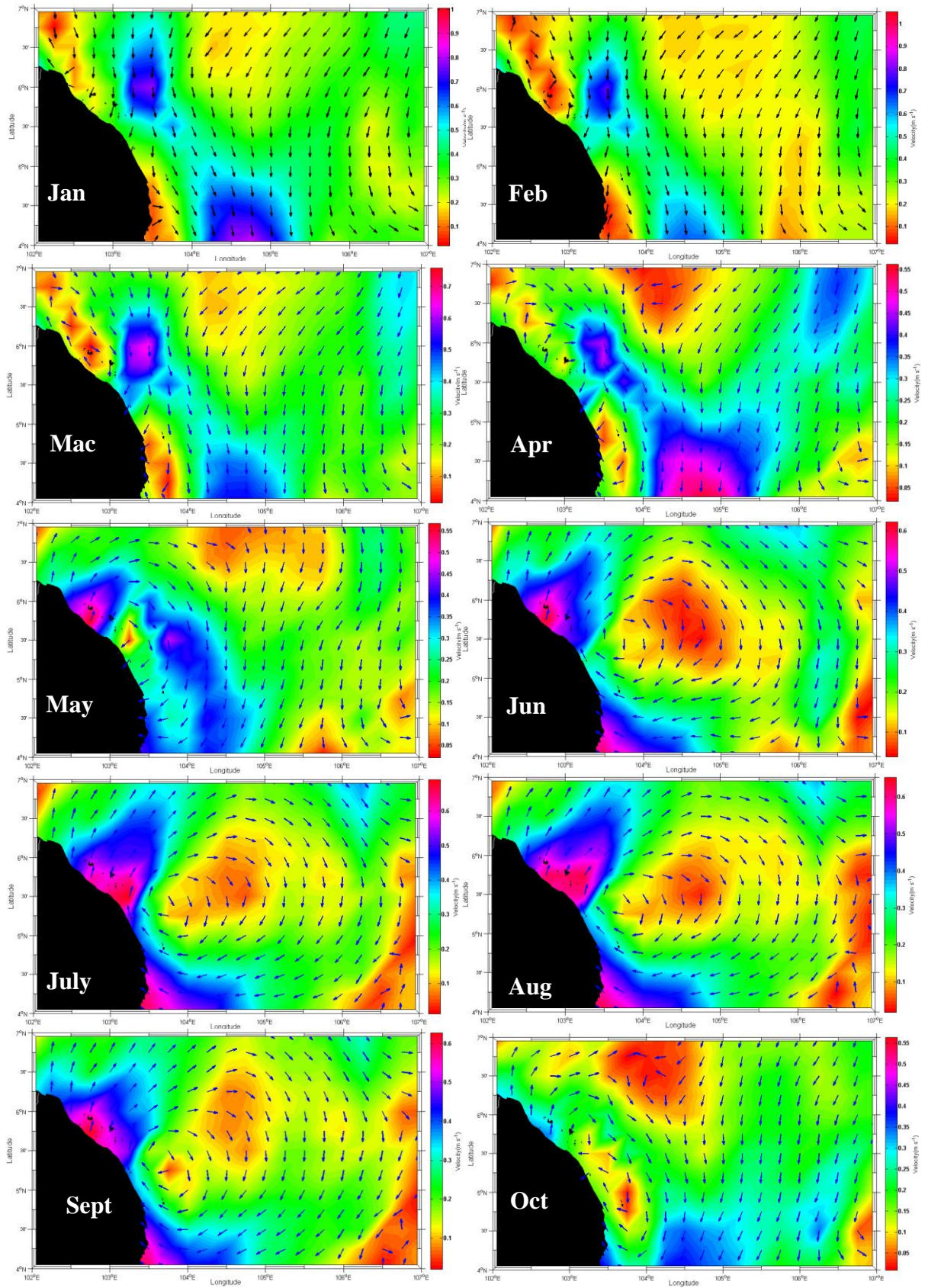


Figure 7 Monthly average geostrophic current from January to October

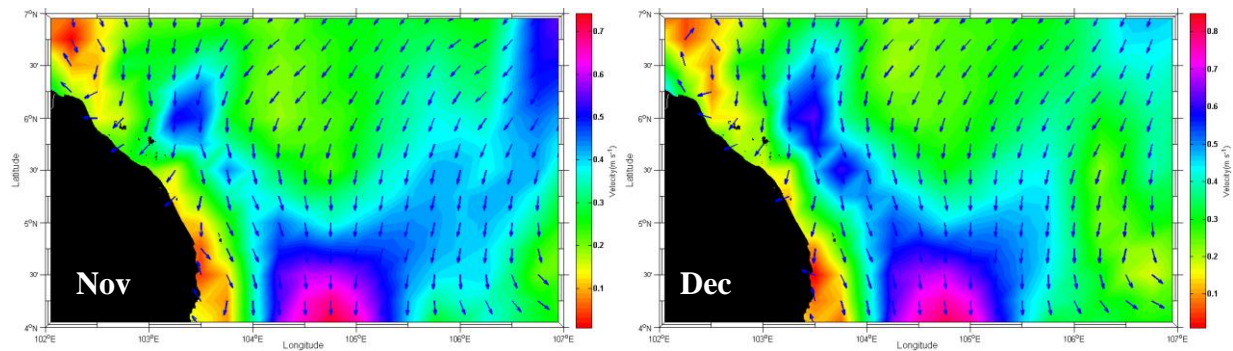


Figure 8 Monthly average geostrophic current for November and December

5.0 CONCLUSION

The present study derives the surface circulation along Eastern Continental Shelf of Peninsular Malaysia using altimeter data. The geostrophic current pattern derived from the altimeter data agrees well with the drifter moving pattern. The surface circulation patterns during the NE and SW monsoons are in opposite directions, northward and southward respectively. During the SW, an anti-cyclonic eddy has been detected around the Terengganu coastal area centred at (about 5.5° N 103.5° E). Comparison of the surface current pattern during NE Monsoon with the drifting buoys have confirmed the VCC and circulation pattern along east of Peninsular Malaysia. Also, ocean current data from ADCP observations in the southern of Peninsular east coast during SW Monsoon is consistent with the surface current pattern derived in this study.

Acknowledgments

The authors would like to thank the TUDelft NOAA and Altimetrics LLC for providing altimetry data. Special thanks are due to MOHE, UTM & VOTE NO.(00J78). The 1992-2002 mean ocean dynamic topography data has been obtained from Nikolai Maximenko (IPRC) and Peter Niiler (SIO).

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