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Euphotic Depth Zone Variation in Peninsular Malaysia Maritime

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Abstract

This study is conducted in Peninsular Malaysia maritime to investigate the euphotic zone depth (Z_{eu}) variation and the possible suspended matter that may contribute to the variation. The Z_{eu} data were acquired from the MODIS Aqua satellite from November 2002 to September 2013. The result shows that the Z_{eu} along the Malaysia maritime are highly seasonal-dependent. The lowest Z_{eu} values are observed during the northeast monsoon season (NEMS) in the east coast Peninsular Malaysia and during the southwest monsoon season (SWMS) for the west coast area. Chlorophyll-a (Chl-a) and colored dissolved organic matter (CDOM) are found to be the contributing factors for the coastal line and open water area. While, sediment only contributes to the area located along the coastal line where lower Z_{eu} values are observed.

Keywords: Euphotic zone depth, MODIS, sediment, monsoon

1 Introduction

Water clarity is one of the physical water optical properties and traditionally measured by using Secchi disc technique [8]. Such measurements are usually carried out using research cruises, which have limited temporal and spatial accessibility. With the advancement of the remote sensing technology such limitations can be solved; recently, MODIS OBPG have distributed euphotic zone depth (Z_{eu}) product through Giovanni interface that can be used to monitor water clarity in ocean. Theoretically, Z_{eu} is defined as the depth of a water body at which the light intensity is reduced to 1% from the value at the surface [4], [9]. Z_{eu} depends on the suspended matter in the water body (i.e. high suspended sediment concentration can decrease Z_{eu} and vice versa), therefore is a good indicator to monitor the clarity of the water body. The suspended matter can be in a form of sediment, dead organic material or phytoplankton. Although the product can indicate water clarity (or turbidity), it cannot specifically tell the type of suspended matter that affects the Z_{eu}. Determining the possible suspended sediment that contributes to the variation in Z_{eu} is an interesting but challenging task. Generally, there are two common methods to estimate Z_{eu} using remote sensing techniques [9], [5]. The first method is the simple Chl-a approach, which is an empirical method that is based on assumption by Morel et al. [5]. By using this method, the Chl-a concentration can be used to calculate Z_{eu} based on the fact that a euphotic zone provides a suitable place for marine phytoplankton to photosynthesize. Lee at al. [9] has developed a different approach that made use of water inherent optical properties (IOP). This developed method is named IOP-Centered approach. In this method, Z_{eu} is computed based on the absorption and backscattering coefficients at 490 nm. The performance both methods have been tested in the East China Sea by Shang et al. [7]. The results showed that both methods were robust, with the IOP-Centered approach was found more reliable. The main objectives of this study are therefore to monitor Z_{eu} variation in Peninsular Malaysia maritime and determine the possible suspended matter that contribute to the variation of Z_{eu}. In this study, data acquired from MODIS Aqua from 2002 to 2013 is used. The study is conducted by making use of Giovanni online interface.

2 Materials and Methods

Peninsular Malaysia is part of Malaysia, covering an area of 131,598 square kilometres. It shares a land border with Thailand to the north while to the south is the island of Singapore. Across the Strait of Malacca to the west lies the island of Sumatra, Indonesia. Malaysia's climate is influenced by the wind systems that originate from Indian Ocean and South China Sea. Every year, southwest monsoon season (SWMS) and northeast monsoon season (NEMS). SWMS occurs from May to September and brings rain to the west coast of Peninsular Malaysia, while NEMS occurs from November to March and brings rain to the east coast of Peninsular Malaysia. Figure 1 shows the bathymetry map for the study area [2].

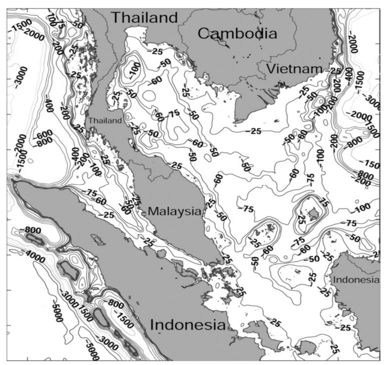


Fig. 1. Bathymetry map of Peninsular Malaysia. Depth contours are in meters.

The data for Z_{eu}, $R_{rs}(667)$, Chl-a and CDOM are initially explored by using Giovanni system. Giovanni is a Web-based online visualization and analysis tool that allows a user to browse Earth science remote-sensed and numerical models data from multitemporal and multiresolution acquisition systems. The Giovanni products are updated routinely to provide the most recently available data, thus benefiting users in carrying out short and long terms research. In this study, the coordinates of the study area are from 1^oN to 6.5^oN latitude and from 98.5^oE to 106^oE longitude covering the whole Peninsular Malaysia. This study makes use multitemporal dataset downloaded from the Giovanni system. MODIS Aqua data that were resampled at 4 km resolution from November 2002 to September 2013 are used. Z_{eu} can be derived by using Lee et al. [9] algorithm, which is based on the IOP approach:

$$Z_{eu} = \frac{4.605}{K_{PAR}(Z_{eu})} \tag{1}$$

where, K_{PAR} is the vertical attenuation coefficient of photosynthetic available radiation (PAR). Remote sensing reflectance at 667 μm wavelength, $R_{rs}(667)$ is used as an indicator to indicate the presence of suspended sediment in the study area [1], [3], [6], where remote sensing reflectance R_{rs} at wavelength λ can be defined as:

$$R_{rs}(\lambda) = \frac{L_W(\lambda)}{E_s(\lambda)} \tag{2}$$

where, $R_{rs}(\lambda)$ is the above water remote sensing reflectance, $L_W(\lambda)$ is the water leaving radiance and $E_s(\lambda)$ is the above-water incident irradiance. Chl-a concentration acquired from MODIS Aqua sensor is used to indicate the presence of phytoplankton in the study area. The MODIS Aqua data are from the period of November 2002 to March 2013. The Chl-a concentration is determined using OC3M algorithm that is extended from the OC4 and OC2 algorithms that were originally developed for SeaWiFS sensor [3]. The OC3M algorithm is defined as:

$$[\mathrm{Chla}]_P = f(R_{3M}) = 10^{(0.283 - 2.753R_{3M} + 1.457R_{3M}^2 + 0.659R_{3M}^3 - 1.403R_{3M}^4)} \tag{3}$$

$$R_{3M} = \log_{10} \frac{\max[R_{rs}(443\mathrm{nm}), R_{rs}(488\mathrm{nm})]}{R_{rs}(551\mathrm{nm})} \tag{4}$$

$$R_{rs}(\lambda) = \frac{L_W(\lambda)}{E_s(\lambda)} \tag{5}$$

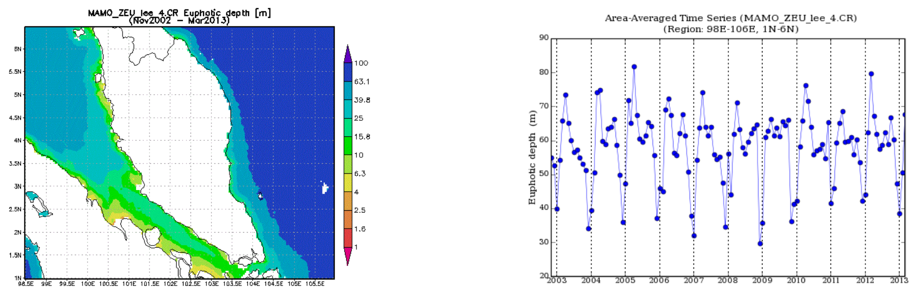
where, $[\mathrm{Chla}]_P$ is the Chl-a concentration estimated at pixel's scale, $L_W(\lambda)$ is the water leaving radiance and $E_s(\lambda)$ is the above-water incident irradiance. MODIS Aqua CDOM index product is used as a indicator to the present of the above mention suspended matter in the study area. This product was generated by OBPG by using a simple band ratio algorithm [5].

3 Results and Discussion

The first section discusses the Z_{eu} variation, while the second section discusses the possible constituents that may cause the variation.

3.1 Z_{eu} Variation

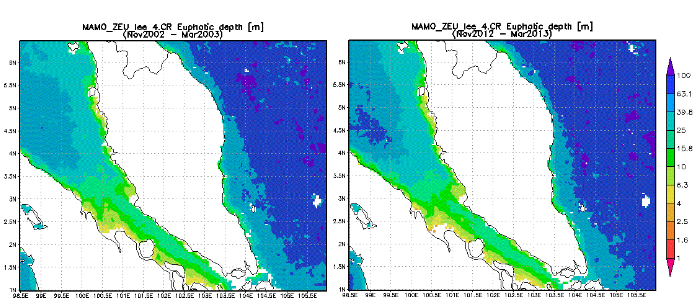
Figure 2(a) shows the Z_{eu} image for the period from November 2002 to March 2013. In overall, high turbid water areas can be seen along the coastal line and in the lower water area with the Z_{eu} values ranging from 1 to 100 m. The turbid water area in the east coast of Peninsular Malaysia shows a different pattern as compared to the west coast area. In the east coast region, highly turbid water is observed along the coastal line stretching from Kelantan at the north to Johor at the south. Along the east coast coastal line, the Z_{eu} values range from 10 to 15.8 m. Far from the coastal line, the turbidity decreases and the Z_{eu} increases until as high as 100 m. For the western side of Peninsular Malaysia, the Z_{eu} varies from south to north. The high turbidity zone is observed along the Straits of Malacca but further to the northwest, the zone decreases. The Z_{eu} values for this area are from 4 to 63 m.



(a) (b)

Fig. 2. (a) Z_{eu} for November 2002-March 2013 and (b) Area-averaged time series of Z_{eu} for 2003-2013.

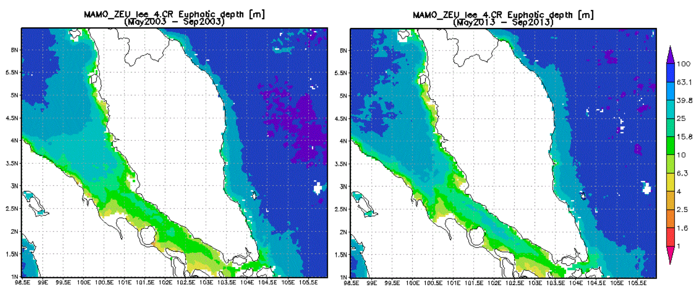
Figure 2(b) shows the area-averaged time series of Z_{eu} for the study period. The highest Z_{eu} value is observed in April (2003-2009, 2011-2012), while, for the year of 2010, the highest Z_{eu} value occurs in May. The highest Z_{eu} value ranges from 70 to 80 m. The Z_{eu} starts to decrease to the lowest value in December (2003-2005, 2007-2009, 2011) and January (2003, 2007, 2011, 2012). The lowest Z_{eu} values are in the range of 30 to 40 m. Figure 3(a) shows the Z_{eu} image during the NEMS for the period from November 2002 to March 2003. The Z_{eu} image for the period from November 2012 to March 2013 is shown in Figure 3(b). The turbid water area is apparently wide within NEMS period especially along the coastal line of Peninsular Malaysia east coast region. During this period, the Z_{eu} value reaches as low as 6.3 m. The turbid water area covers coastal water line from Kelantan at the north to Johor at the south. Regarding the distance from the coast line, the Z_{eu} pattern is almost the same with the Z_{eu} image in Figure 2(a). In the clear water region, the Z_{eu} values are from 25 to 63 m. For the western part of Peninsular Malaysia, the Z_{eu} trend remains the same as in Figure 2(a). The Z_{eu} pattern for the period from November 2002 to March 2003 remains the same as Z_{eu} pattern for the period from November 2012 to March 2013.



(a) (b)

Fig. 3. Z_{eu} for (a) November 2002-March 2003, (b) November 2012-March 2013.

Figure 4(a) shows the Z_{eu} image during SWMS from May to September 2003. As compared to Figure 2(a), the turbid water area increases, especially at the north of the Malacca Straits. The same Z_{eu} pattern is observed for the May 2013 to September 2013 image as shown in Figure 4(b). The Z_{eu} values towards the south of Malacca Strait are almost the same with Figure 2(a) for both 2003 and 2013 NEMS. Monsoonal comparison shows that the wide area of low Z_{eu} values are observed along the east coast region for the May to September 2013 as compared to the May to September 2003 monsoon season. The turbid water area for the May to September 2013 is found to be decreasing.

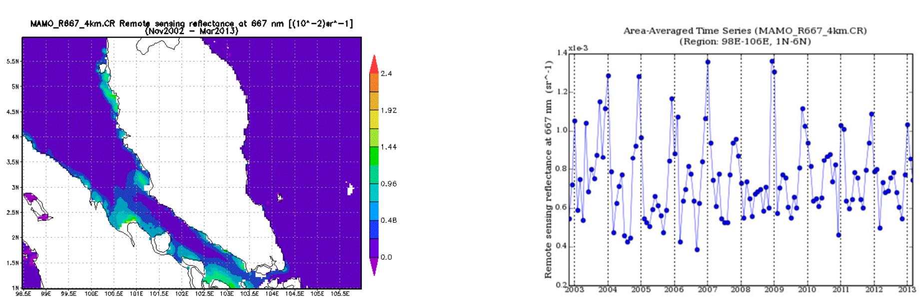


(a) (b)

Fig. 4. Z_{eu} for (a) May 2003-September 2003 and (b) May 2013-September 2013.

3.2 Possible Constituents

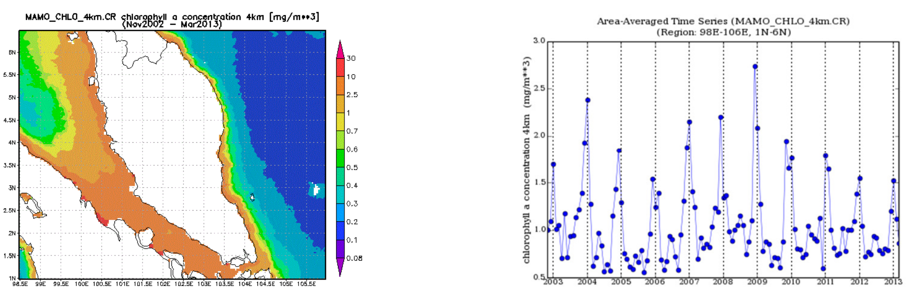
There are a number of factors than may contribute to the variation in the Z_{eu} value in the study area. Here, we investigate the possible contribution factor. Figure 5(a) shows the $R_{rs}(667)$ in the study area for the period from November 2003 to March 2013. This Figure shows that the R_{rs} values are higher along the west coast of Peninsular Malaysia and along the Sumatra coastal line compared to other locations. R_{rs} values along the east coast of Peninsular Malaysia coastal line are quite constant. When compared to Figure 2(a), the high turbidity areas seem to be represented by high $R_{rs}(667)$. For moderate Z_{eu} values, no correlation is observed. Figure 5(b) shows the $R_{rs}(667)$ values observed from December to January every year. The highest R_{rs} value occurs concurrently with the lowest Z_{eu} value.



(a) (b)

Fig. 5. (a) $R_{rs}(667)$ for November 2002-March 2013 and (b) $R_{rs}(667)$ area-averaged time series for 2003-2013.

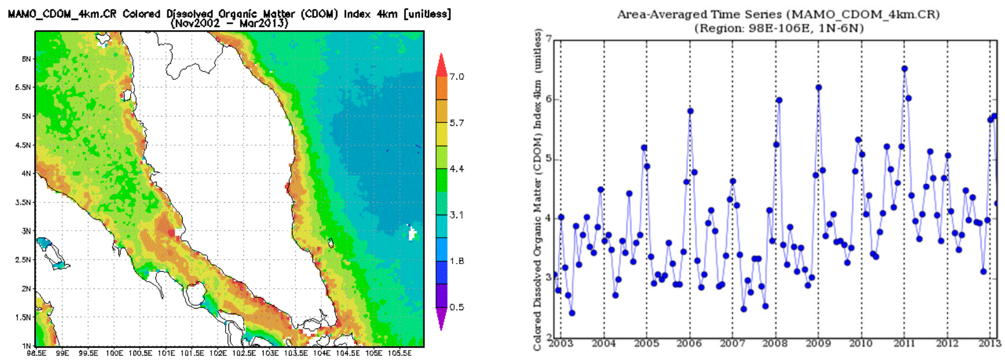
The other factor that may lead to the turbidity variation is the present of phytoplankton, which can lower the Z_{eu}. In this study, the Chl-a values are used as an indicator to the presence of phytoplankton in the water body. Figure 6(a) shows the Chl-a concentration in the study area for the period from November 2003 to March 2013. The result shows that high Chl-a concentrations are observed along the Malacca Straits and along the east coast Peninsular Malaysia. The Chl-a value in this area varies between 0.2 to 30 mg/m^3. Low Chl-a concentrations are observed in the South China Sea. As compared to Figure 2(a), this result indicates that the low Z_{eu} values occurred concurrently with the high Chl-a dominated area. This shows that, the Z_{eu} are highly correlated with the presence of phytoplankton. The Chl-a area-averaged time series that is shown in Figure 6(b) also shows high correlations with the Z_{eu}. Higher Chl-a concentrations are observed from December to January every year. These peak months are consistent with the months having the lowest Z_{eu} values.



(a) (b)

Fig. 6. (a) Chl-a concentration for November 2002-March 2013 and (b) Chl-a area-averaged time series for 2003-2013.

Figure 7(a) shows CDOM variation in the study area for the period from November 2002 to March 2013. High CDOM values are observed in the Malacca Straits, along the west coast and east coast of Peninsular Malaysia. In this area, the CDOM values are from 4.4 to 7. In the west coast of Peninsular Malaysia, the lowest CDOM is below 4.4. Low CDOM area is observed at the top left of the image; this area is considered as open water regions that are located far from the coastal line. In the east coast of Peninsular Malaysia, high CDOM values are observed along the coastal line where the highest CDOM values are observed near river estuaries in Pahang and Kelantan. Based on the knowledge of the study area, it is known that, the discharge carried by the rivers contains much CDOM. As expected, the CDOM value shows a decreasing trend at open water area. The CDOM values in the open water area are from 1.8 to 3.1. As compared to Figure 2(a), the Z_{eu} and CDOM variation are highly correlated especially at the low Z_{eu} area. The area-averaged time series for these two parameters show a highly inverse correlation. The high monthly CDOM values are found corresponding with the low monthly Z_{eu} values.



(a) (b)

Fig. 7. (a) CDOM concentration for November 2002-March 2013 and (b) CDOM area-averaged time series for 2003-2013.

4. Conclusion

In this study, Z_{eu} variation for Peninsular Malaysia from November 2002 to September 2013 is investigated. Lower Z_{eu} values are observed in the west coast compared to the east coast area. In the east coast area, low Z_{eu} values are observed along the coastal line, while high Z_{eu} values are observed far from the coastal line. It is also found that Z_{eu} values are highly seasonal-dependent. During NEMS, lower Z_{eu} values are observed along the east coast coastal line for the monsoon period from November 2002 to March 2003 and this pattern is repeated for the monsoon period from November 2012 to March 2013. This is also true for SWMS that occured from May to September within the study period. The sediment detected by $R_{rs}(667)$ is correlated with Z_{eu} especially along the west coast coastal line of Peninsular Malaysia. However, sediment does not contribute to euphotic zone variation in the east coast of Peninsular Malaysia. The Z_{eu} variation is influenced mainly by the presence of phytoplankton, as indicated by the Chl-a concentration, for both side of Peninsular Malaysia. Low Z_{eu} values are observed at the areas of high Chl-a concentration, i.e. coastal and open water regions. It is also found that CDOM also contributes to the variation in water clarity where high correlation between these parameters is found. Finally, it can be concluded that the water clarity in Peninsular Malaysia maritime is highly seasonal-dependent. The phytoplankton and CDOM are the main factors that contribute to the clarity of coastal and open water regions. Sediment concentrations only affect the water clarity along the coastal lines.

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