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INTERANNUAL VARIATION OF CHLOROPHYLL-A CONCENTRATION IN THE EXCLUSIVE ECONOMIC ZONE WATERS OF PENINSULAR MALAYSIA

MUSTAPHA, M.A.*, LIHAN, T. and ZAMBARI, I.F.

School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
**E-mail: muzz@ukm.edu.my*

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ABSTRACT

Chlorophyll-a concentration is one of the major indicators of phytoplankton production in the ocean. Identification of chlorophyll-a distribution and productivity is important to understand physical and biological processes in the ocean. The objectives of this study are to determine the spatial and temporal distribution of chlorophyll-a and to identify influence of sea surface temperature (SST) and current on chlorophyll-a concentration variation in the Exclusive Economic Zone (EEZ) waters of Peninsular Malaysia. Satellite data of chlorophyll-a concentration and SST (2007 to 2014) were derived from MODIS-Aqua and geostrophic current was obtained from NOAA Ocean Watch. Empirical Orthogonal Function (EOF) analysis was used to determine the spatial and temporal variation of chlorophyll-a. Five modes represented the variation of chlorophyll-a. Mode 1 (60.62%) explained seasonal pattern, Mode 2 (27.83%) indicated patterns during the southwest monsoon, Mode 3 (19.96%) highlighted the inter monsoon of northeast to southwest. Mode 4 (19.57%) represented the northeast monsoon and Mode 5 (18.98%) explained inter monsoon of southwest to northeast. Variation of chlorophyll-a concentration was influenced by variability in SST and current during the monsoons. Variability in magnitude and direction of current circulation was observed to affect SST distribution thus influences concentration and distribution of chlorophyll-a.

Key words: chlorophyll-a, spatial variability, EOF, Exclusive Economic Zone

INTRODUCTION

Chlorophyll-a concentration is one of the major indicators of phytoplankton production in the ocean. High chlorophyll-a concentration refers to the high productivity, strong fertility and stability of the ocean. Determination of chlorophyll-a distribution and productivity is important to understand physical and biological processes in the ocean. Chlorophyll-a is the pigment involved in phytoplankton photosynthesis and it has been widely used to determine phytoplankton distribution in the ocean (Yoder & Kennely, 2003). Variation in chlorophyll-a concentration has been reported over large areas using remote sensing applications. Many studies have examined the chlorophyll-a distribution changes in the ocean through ocean colour satellites. Variation of chlorophyll-a concentration using ocean colour satellite images (SeaWiFS) over 12 years (1997-2008) in the South Western Atlantic has been reported (Machado *et al*., 2013). Long-term changes in chlorophyll-a concentration in Taihu Lake, China from 2004 to 2011 based on EOF analysis using MODIS satellite have been estimated (Qi *et al*., 2014). Moses *et al* (2009) also analysed MODIS and MERIS satellite data to estimate the chlorophyll-a biomass in the Dniper River and Sea of Azov in Russia. Chlorophyll-a concentration in the east coast of Peninsular Malaysia based on SeaWiFS data of August 2000 have been previously estimated (Asmat *et al*., 2002).

Chlorophyll-a concentration in the surface of the ocean is declining globally since the past century due to global warming. Chlorophyll-a influences 46% of annual primary production of the ocean and changes of chlorophyll-a concentration impacts the global carbon cycle (Henson *et al.*, 2010). Thus understanding variation in chlorophyll-a concentration and factors influencing its variation is important. The objectives of this study are to determine the spatial and temporal variation of

* To whom correspondence should be addressed.

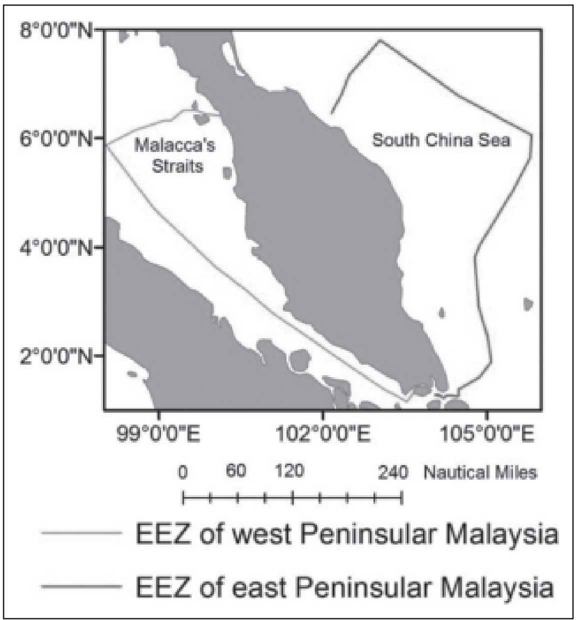

Fig. 1. Map indicating location of study area in the EEZ waters of Peninsular Malaysia.

chlorophyll-a concentration and distribution in the EEZ waters of Peninsular Malaysia and to identify factors influencing its variation.

MATERIALS AND METHOD

Study Area

The study area covers the EEZ waters of Peninsular Malaysia in the Straits of Malacca and South China Sea between 1° N to 8° N latitude and 98° E to 106° E longitude (Figure 1). EEZ total area of west coast Peninsular Malaysia is 68,747 km^2 with depth exceeding 120 m. Whereas EEZ total area of east coast of Peninsular Malaysia is 132,973 km^2 at 70 m maximum depth.

Satellite Data

Level 3 monthly MODIS derived chlorophyll-a concentration and sea surface temperature (SST) data at 4 km resolution from January 2007 to December 2014 were acquired from the website of NASA's Ocean Colour (www.oceancolor.gsfc.nasa.gov). Meanwhile sea surface current data at 0.25^o resolution was obtained from the NOAA Ocean Watch Central Pacific. Monthly data was acquired from their website (oceanwatch.pifsc.noaa.gov) which provides satellite data observation for oceanographic study.

The chlorophyll-*a* concentration and SST satellite images were processed using SeaWiFS Data Analysis System (SeaDAS). The chlorophyll-a data were interpolated to cover missing data due to cloud cover or extreme weather. Interpolation is a procedure used to predict the values of cells at a location. This procedure is important to derive more accurate result of spatial data. ERDAS Imagine interpolation tool was used to generate a surface grid. The weighted value of points inside the neighbourhood was calculated using distance weighted interpolation. The data was then composited to climatology data to study the variation of chlorophyll-a concentration. Composite analysis is a simple method used to develop the point of variability in the data (Bjornsson & Venegas, 1997).

Empirical Orthogonal Function (EOF) analysis

Empirical Orthogonal Function (EOF) is a technique to reduce large number of variables of an original data to a few variables that capture most of the observed variance from the data. EOF is important in atmospheric science in order to analyse the problem in processing the meteorology and oceanography data. EOF analysis allows compressing complex and large amounts of covariance matrix data and representing it into a number of modes. The covariance matrix size is compressed without much information loss. Each empirical modes or orthogonal function is formed by a spatial pattern and time series derived from the eigenvalues and eigenvectors of the covariance matrix (Bjornsson & Venegas, 1997). Monthly composite chlorophyll-a images were standardized by ignoring the monthly mean from the time-series and decomposed using the method of Polovina & Howell (2005):

$$F(x, t) = \sum_{i=1}^{N} a_i(t)\, c_i(x)$$

where $a_i(t)$ are the principal component time-series or the expansion coefficients of the spatial components $ci(x)$. The temporal and spatial components are calculated from the eigenvectors and Eigen functions of the covariance matrix **R**, where **R=F'·F.** This analysis results in *N* statistical modes, each with a vector of expansion coefficients related to the original data time-series by $a_i=Fc_i$ and a corresponding spatial component map $c_{i.}$

RESULTS AND DISCUSSION

The chlorophyll-a concentration and distribution in the EEZ waters of Peninsular Malaysia showed spatial and temporal variation from January 2007 to December 2014. Chlorophyll-a concentration was dominant at west coast compared to east coast as observed in the chlorophyll-a climatology image (Figure 2). During Southwest monsoon, chlorophyll-a concentration was lower in the Straits of Malacca and South China Sea compared to Northeast

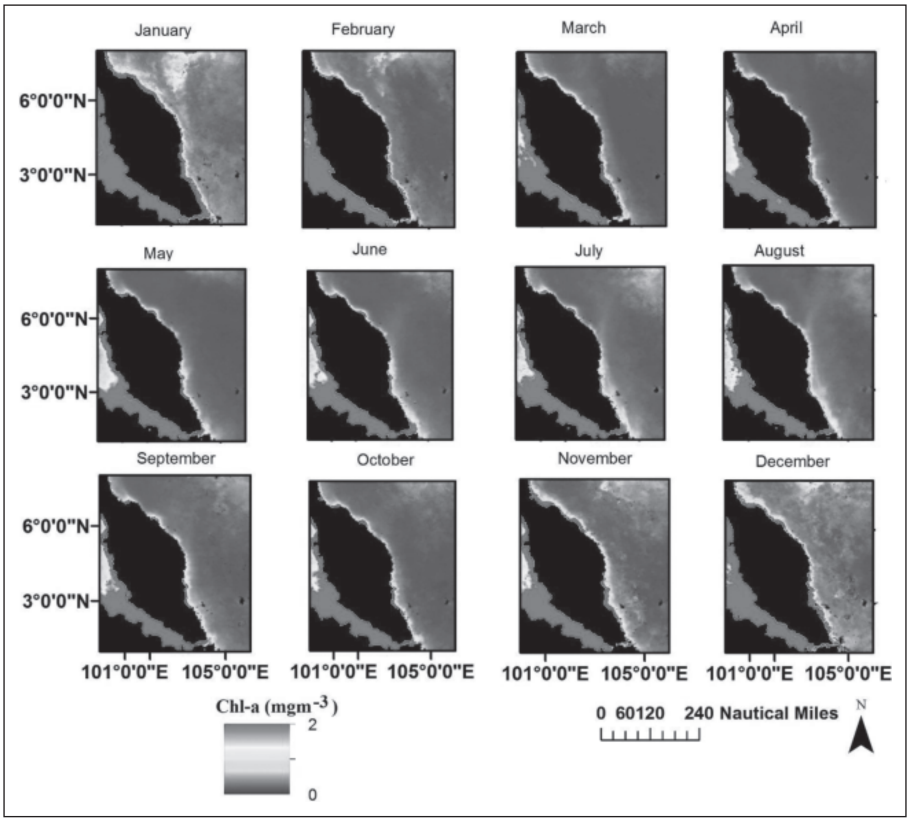

Fig. 2. Climatology images of Chlorophyll-a concentration and distribution in the EEZ waters of Peninsular Malaysia from January 2007 to December 2014.

monsoon. In May, the chlorophyll-a concentration value was 0.14 mgm^{-3} which was the lowest compared to other months and it occurred in the centre of east coast and north of Malacca Straits towards Andaman Sea. Following months of June, July, August and September, the chlorophyll-a concentration recorded values of 0.15, 0.22, 0.18 and 0.19 mgm^{-3} respectively. In July, increased in chlorophyll-a concentration was observed at south of east coast. During inter monsoon of southwest to northeast, chlorophyll-a concentration increased slightly to 0.21 mgm^{-3} at the north of east coast. During Northeast monsoon, increased in concentration of chlorophyll-a occurred at the north of east coast and southern coast. Concentration was at 0.30 mgm^{-3} and 0.40 mgm^{-3} in November and December respectively at the north of east coast. The coastline of east coast and west coast of Peninsular Malaysia also indicated high chlorophyll-a concentration. The chlorophyll-a concentration declined as it enters the inter monsoon of northeast to southeast.

The chlorophyll-a variability was also demonstrated by the EOF analysis. Five modes represented the spatial pattern and temporal variation of chlorophyll-a concentration in the EEZ waters of Peninsular Malaysia from January 2007 to December 2014 (Figure 3). The temporal and spatial pattern showed EOF analysis for mode 1 with variance value of 60.62%. The highest signal occurred at the south of west coast and north of east coast. The lowest signal was observed at offshore areas of east coast. Positive high peak occurred in February 2007, June 2008, January 2009, February 2010, July 2011, January 2012, December 2013 and January 2014. Whereas, positive low peak occurred in July 2007, September 2008, September 2009, December 2010, September 2011, September 2012, September 2013 and September 2014. EOF mode 1 explained seasonal pattern. The EOF analysis of mode 2 indicated variance value of 27.83%. The highest signal was at south part of the Straits of Malacca and southern of east coast Peninsular Malaysia. Positive high peak occurred in July 2007, May 2008, June 2009, September 2010, August 2011, August 2012, July 2013 and June 2014.The variation of EOF mode 2 represented the southwest monsoon. EOF analysis mode 3 showed variance value of 19.96%. Positive high peak occurred in May 2007, February 2008, May 2009, May 2010, May 2011, June 2012, May 2013 and June 2014. Highest signal occurred at the northern and southern of west coast and east coast. EOF mode 3 explained inter- monsoon of northeast to southwest.

Mode 4 with variance value of 19.57% showed negative high peak at northern and southern of west

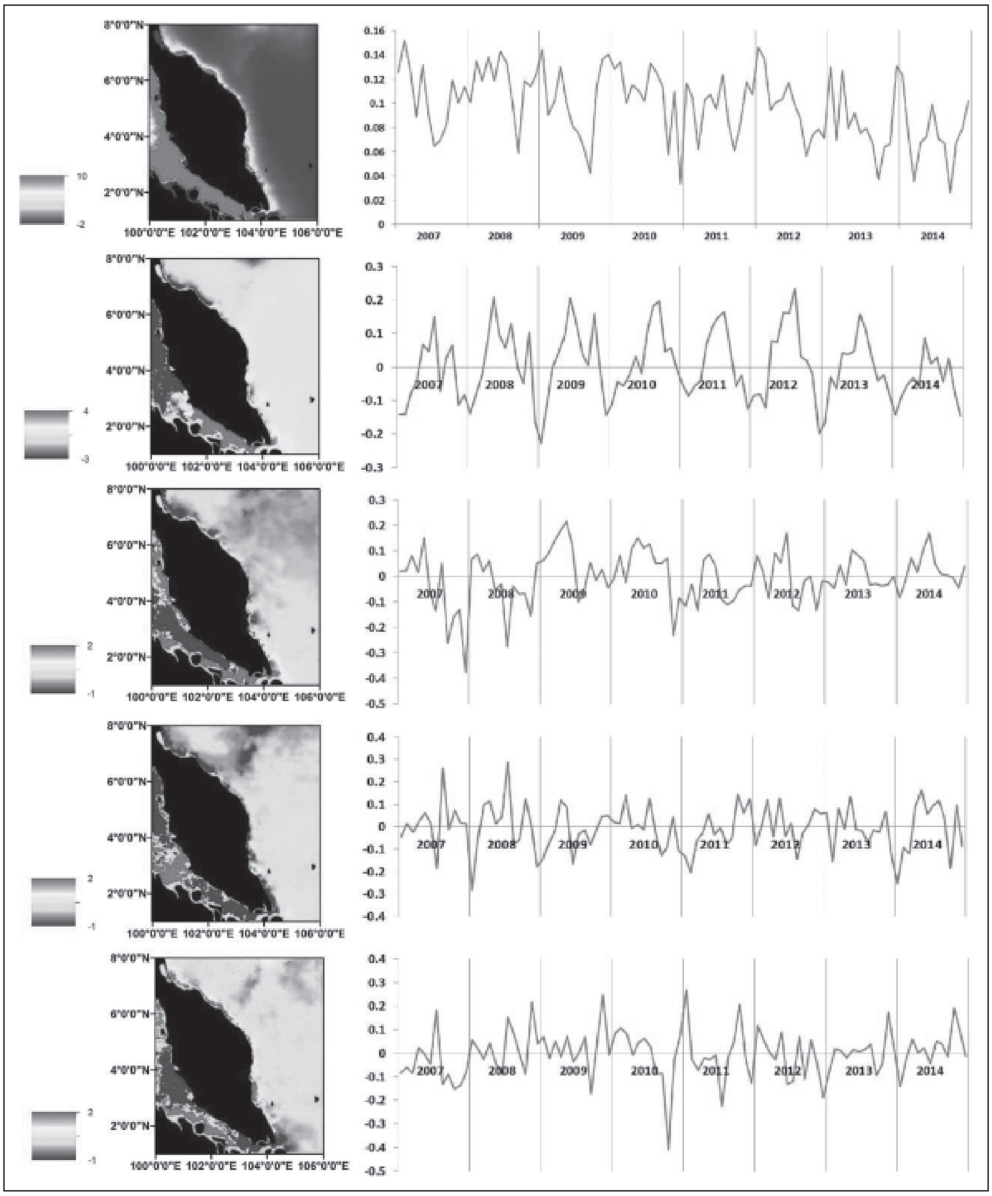

Fig. 3. EOF analysis showing inter-annual variability of Chlorophyll-a in the EEZ waters of Peninsular Malaysia: Each mode consist of spatial pattern (left) and the time-series (right).

coast and along the coastline of east coast. Negative high peak occurred in July 2007, January 2008, June 2009, September 2010, February 2011, August 2012, February 2013 and January 2014. EOF mod 4 explained the Northeast monsoon. Meanwhile, EOF analysis for mode 5 indicated value of 18.98%. Highest negative signal was at middle of west coast and southern of Peninsular Malaysia. Negative high peak occurred in October 2007, October 2008, September 2009, October 2010, July 2011, December 2012, September 2013 and January 2014. This mode represented variation during the inter-monsoon of southwest to northeast.

During southwest monsoon, high chlorophyll-a concentration occured in the shallow part of southern west and east coast of Peninsular Malaysia (Figure 4a). The coastline has many rivers that flow out to the sea which bring nutrients and indirectly enhancing chlorophyll-a distribution (Hii *et al.*, 2006). The shallow part of southern coast of Peninsular Malaysia indicated presence of strong current circulation that enhances mixing of nutrient and sediments from Malacca's Straits waterways and South China Sea. This causes well distributed chlorophyll-a concentration at the southern part (Behera *et al.*, 2013). The southwest monsoon brings warmer water into the Straits of Malacca from Karimata Straits towards Andaman Sea (Ibrahim & Yanagi, 2006). This resulted in the increase of SST observed.

During the Northeast monsoon, the north easterly current circulation flows from south of

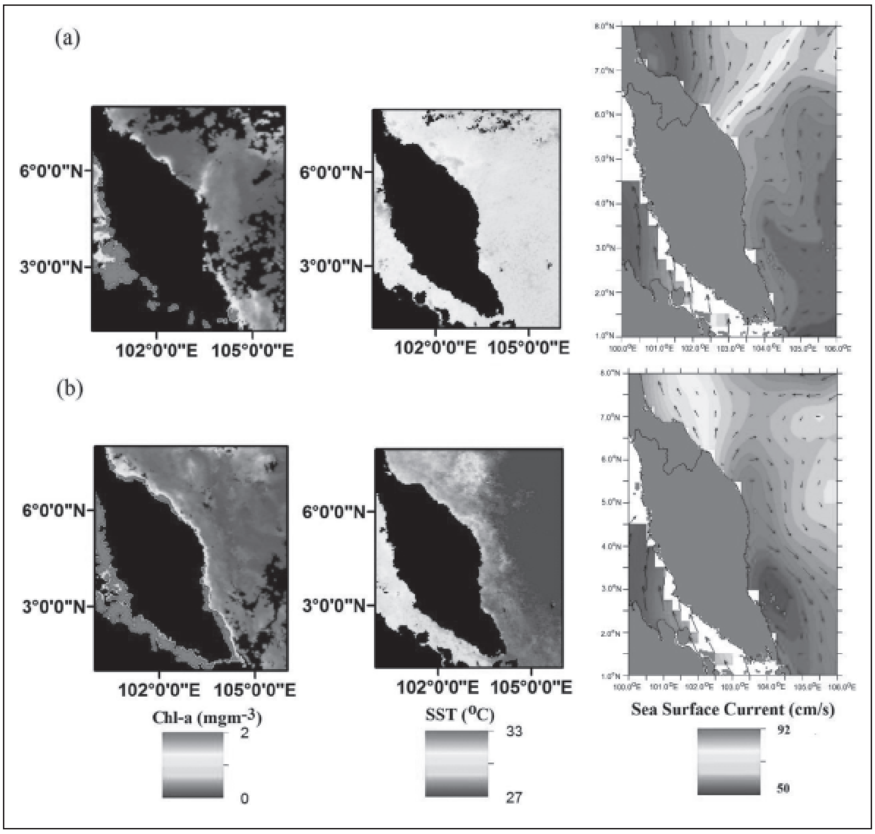

Fig. 4. Chlorophyll-a concentration, SST and sea surface current in the EEZ waters of Peninsular Malaysia (a) in August 2007 (representing the Southwest monsoon) and (b) in January 2008 (representing the Northeast monsoon).

Vietnam and moves wider as approaching the coastline of Peninsular Malaysia (Figure 4b). The strong current flow brings cool water southward (Akhir *et al.*, 2014). It also carries the monsoon rain to Southeast Asia and increases river run off along the coast. This increases mixing of nutrient and contributes to the growth of phytoplankton. High chlorophyll-a concentration can be observed along the coastline of east Peninsular Malaysia (Amin *et al.*, 2014). Meanwhile in the Straits of Malacca, strong current from north moves into shallow part of southern Peninsular Malaysia towards to the east coast of Sumatera and causes water mixing in the south of west coast Peninsular Malaysia. This area has higher nutrient level compared to the centre of west coast Peninsular Malaysia. The shallow area of the southern west coast Peninsular Malaysia indicated high phytoplankton productivity (Ibrahim & Yanagi, 2006).

CONCLUSIONS

Five modes of the EOF analysis represented the variation of chlorophyll-a in the EEZ waters. The variation of chlorophyll-a, SST and current circulation are influenced by monsoon. Variability in magnitude and direction of current circulation was observed to affect SST distribution thus influences concentration and distribution of chlorophyll-a.

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