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Application of Remote Sensing Techniques for Studying the Spatial & Temporal Variability of the Pahang River Plume, Malaysia

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ABSTRACT

The Pahang River plume includes chlorophyll a, nutrients, sediments and pollutants, moving to the South China Sea. The objective of this study was to determine the distribution of spatial and temporal patterns of the river plume area. Ocean color data was derived from MODIS satellite data covering the years from 1st January 2005 – 31st December 2010, during the two seasons of the year. Resolution normalized water-leaving radiance, (nLw 551) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua satellite which was the source of suspended-sediment data which had been produced using the Total Suspended Material (TSM) .TSM data shows an inverse relationship with Chl-a data. Which showed that amounts of TSM were the highest during the inter-monsoon period? Also the plume area showed that where Chl-a concentrations were low, elevated chlorophyll a concentration in the offshore area were seen to be influenced by low wind stress. EOF analysis shows only 3 modes that represent the high variability of the Pahang River plume. The first mode (75.8 % of variance) shows that the plume was distributed along the shelf during the inter-monsoon period. Mode 2 (6 % of variance) indicated that the plume was propagated to the northeast during southwest monsoon period and in mode 3 (3 % of variance) the plume was propagated to the south-east during southwest monsoon period. Mode 4 explains about (8.7% variance)indicated that the plume was propagated to the north and northeast during southwest monsoon. Positive signal indicates through the movement of the Pearson correlation analysis the high relationship (r=0.78) between plume area and monthly average precipitation.
KEYWORDS: Monsoon, MODIS,EOF, Chl-a, TSM, wind stress.

INTRODUCTION

Some aspects of condition of the water can be assessed using data obtained in the visible wavelength. Chlorophyll in water increases the reflectance of the green band; monitoring indicates that algal presence and concentration for the shallow water area, sand, mud, and rock at water bottom, organic and inorganic materials in suspension chlorophyll contents will influence the reflectance. Different monsoon periods have different physical ocean parameters such as temperature, salinity and water masses (Pattiaratchi et al., 1994; O'Reilly et al., 1998; Montres-Hugo et al., 2008; Maged and Mazlan, 2010).These parameters led to differences in spatial and seasonal variations of chlorophyll-a concentration along the east coast of peninsular Malaysia. This sort of pattern variation is which a function of the monsoon wind cycle pattern is. Consequently, it is parallel to the seasonal cycle (O'Reilly et al.,1998) .The cycle contains the period of exponential growth and then decreases abruptly, as a result of strong storms. Further, the duration of this cycle is a short-period that ranged between 1 and 2 weeks (Zelina et al , 2000).

Study Area:

The Pahang River or Sungai Pahang in Malay, is located in the state of Pahang, Malaysia (Figure 1) . With 459 km in length, it is the longest river in the Peninsular of Malaysia. The river begins at the confluence of Jelai and Tembeling rivers at the Titiwangsa Mountains and drains into the South China Sea. Annual rainfall of the Pahang River Basin is ranges from 1688 to 2171 mm, The study area coordinates are 102°50' - 104°00'E and 03°10'- 04° 00'N.

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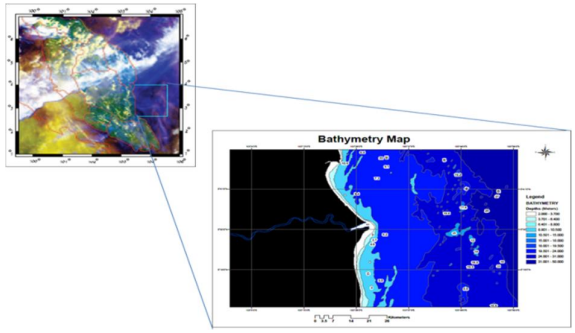


Figure 1: Location of the Study area in the East Coast Peninsular Malaysia, showing the Pahang river and bottom bathymetry.

MATERIAL AND METHODS

a) Chlorophyll Concentration:

The satellite data used in this study are Daily Level 1A MODIS (Aqua) data for the period of 1st January 2005 to 31st December 2010 which were downloaded from the Goddard Distributed Active Archive Center. (http://oceancolor.gsfc.nasa.gov). A total 391 of cloud-free images (61 images in 2005; 88 images in 2006; 42 images in 2007; 51 images in 2008; 57 images in 2009, 49 in 2010) were processed to Level 1, geophysical products , using default NASA coefficients ,local area coverage (LAC) images and community-standard algorithms as implemented by SeaDAS version6.3 software and remapped to a cylindrical projection at 1 km resolution. Daily data were further composited into monthly means for chlorophyll a to study the variability of chlorophyll a concentration. The study area was subset from the images to geographic extents of 2°50′-3°50′N, 103°-104°E. The rules used to define supervised classification training regions are as follows in table (1).

Optical water type	Training criteria
Plume core (class 1)	Immediately off the mouth of the Pahang River (plume area).
Plume and inner (class 2)	Area immediately peripheral to the Plume.
shelf water (class 3)	Area near the coast that is not obviously associated with the plume. High reflectance values in short wave length.
Offshore (class 4)	Area off the shelf with low nLw values in all five bands.

b) River precipitation :

A time series of Monthly precipitation data fromTRMM (Tropical Rainfall Measuring Mission)was obtained by the Goddard Distributed Active Archive Center (GES DISC DAAC).into 0.5 x 0.5 degree gridded monthly from 1 January 2005 to 31 December 2010.

c) Sea Surface wind**:**

Wind data were downloaded from the Southeast Fisheries Science Center, NOAA Fisheries Service Environmental Research from their web site (www.las.pfeg.noaa.gov). These files contain regular grids of zonal and meridional wind speed**s** with 1° spatial resolution at 10 m above the earth's surface. The zonal and meridional wind speeds was used to plot the vector winds. These components were transformed to wind stress, τ (kg m^{-1} sec^{-2}) using the equation of Nezlin and DiGiacomo (2005),τ is the wind stress $=p_a\, C_d\, U^2$

Where τ is the wind stress and $\rho_a$is the air density, U is the wind speed 10 m above the sea surface and $C_d$is the drag coefficient (0.0013).

d) Empirical orthogonal function (EOF) :

To understand the spatial and temporal variability of the river plume empirical orthogonal function (EOF) analysis was applied to time series of the anomaly of nLw(551) monthly averaged images .EOF analysis organizes a time/space series into a set of orthogonal functions that compactly describe the covariability of the data set(Lihan, T. et al 2008).

Images with missing data were interpolated using the Kriging interpolation, which uses weights of the values surrounding the measured value to derive a prediction for unmeasured location.The general formula for this interpolation is formed as a weighted sum of the data according to Equation.

$Z*(S_o)=\sum_{i=1}^{N} \lambda_i Z(S_i)$

Where Z (S_i) is the measured value at ith location,λiis an unknown weight for the measured value at ith location $Z*(S_o)$ is the prediction location and N is the number of measured values.

e) Total suspended material (TSM):

MODIS data were acquired from the NASA MODIS L1 and processed using the NASA SeaDAS software. Level 1A files were subset to contain most of the adjacent drainage basins and coastal area. A file containing MODIS 250 m data (Bands 1 and 2) was then generated using SeaDAS L1B processing, that uses the MODIS

aerosol optical thickness product at 551 nm. The resulting normalized water-leaving radiance (nLw) file (m W/cm2/sr-1/µm) was converted to TSM concentration (mg/L) using a modified version (reflectance to nLw).There was a significant relationship between MODIS-derived TSM concentration and atmospherically corrected red-band reflectance, the larger variation being in TSM concentration at each reflectance value.

RESULTS

1)Chlorophylla concentration in plume area :

The results showed that the chlorophyll_a concentration decreased gradually as it moved away from the coastline and varied with different monsoon seasons. During the northeast monsoon, the plume size was largest of all in November 2010 (1763 km^2) followed by March 2006 (1749 km^2), and the smallest plume size was occurred in August 2006 with area of 397 km^2 followed by February 2005 which was 417$km^2$and separating four spectral classes of coastal water based on optical characteristics in 4 MODIS classes (figure 2). This is in addition to the common distribution of chlorophyll concentration during the study period as showed in (figure4). Range the annual of chlorophyll a concentration was 0.2 - 9.8 mg/m^3 into years 2005 to 2010. (Figure 5).

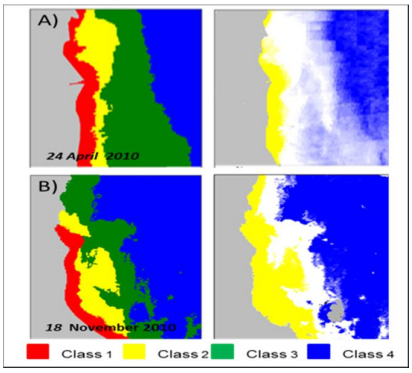
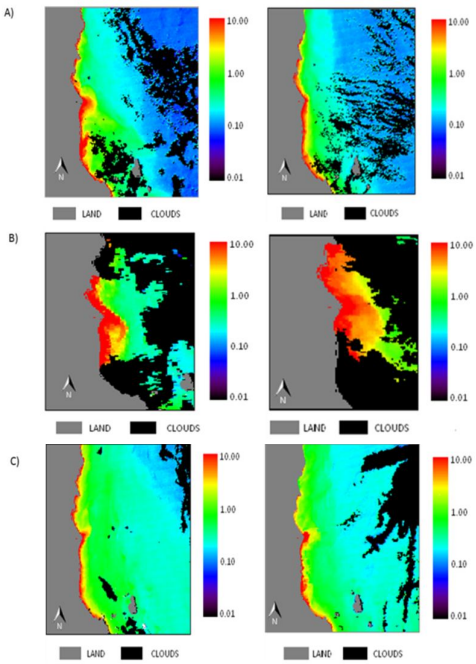


Figure 2) An example false color (down panel) composite of MODIS data (nLw 551 /nLw 488/nLw 443/nLw 412) of the study area showing the spatial pattern and spatial variability of the dominant shelf optical characteristics during a typical monsoon periods situation. The same images after supervised maximum likelihood classification, separating four spectral classes of coastal water based on optical characteristics in 4 MODIS classes.



(Figure 3) Common distribution of chlorophyll concentration during 6-years (2005-2010). A) 24 Apr 2008 (Inter-monsoon), 8 May 2005 (Southwest monsoon) B)23 Nov 2006 , 6 Dec 2009 (Northeast monsoon) C) 18 Aug 2007, 9 Sep 2010 (Southwest monsoon).

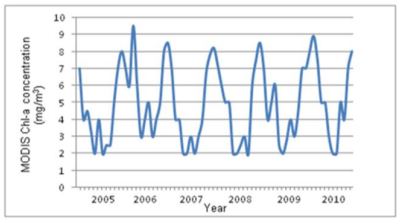


Figure4: Range the annual of chlorophyll a concentration from 2005 to 2010 averaged from monthly images in plume area.

Analyzing the spectral signature from all visible channels showed seasonal variability in surface water optical characteristics between the wet season and dry season .The seasonal differences in spectral signature were characterized by short wavelength (figure4) .During the wet season (November-March). Spectral signatures of class 1, class 2 and class 3 were characterized by high reflectance in the whole visible wavelength .The plume signature is strong with value of nLw 551>3.0 (m W cm^{-2} μm^{-1} sr^{-1}) and other nLw values are low usually <1.0 (m W cm-2 μm^{-1} sr^{-1}).

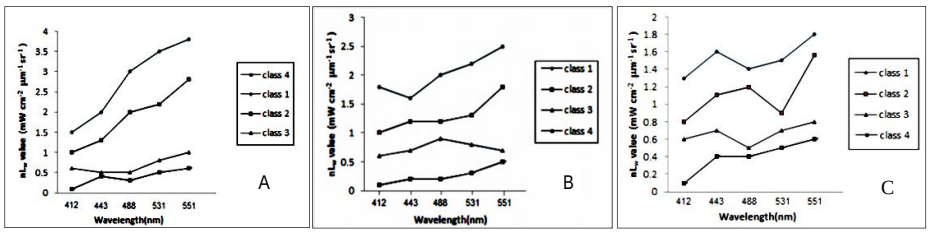


Figure5) the mean spectral signature of plume area, where; A) high nLw 551value in wet season. B) High nLw 551values in dry season. C) Low nLw 551 values in both seasons to each of the four optical classes. The two types of graphics A & B are representative to high spectral reflectance during strong wind event.

2) Total suspended material (TSM):

The high variation in TSM concentration occurs in the low reflectance value. TSM within the range of 0.8 – 33.86 mgl^{-1} (Figure 6) shows the inverse relationship between the total suspended material and chlorophyll concentration. The spatial distribution of the wet season plume had mainly a south-west orientation. On the basis of the spatial distribution of four water spectral classes the following water types were identified (Figure 7): (1) the immediate plume core; (2) the plume edges and near shore waters; (3) the peripheral plume and the inner shelf water; (4) the offshore water.

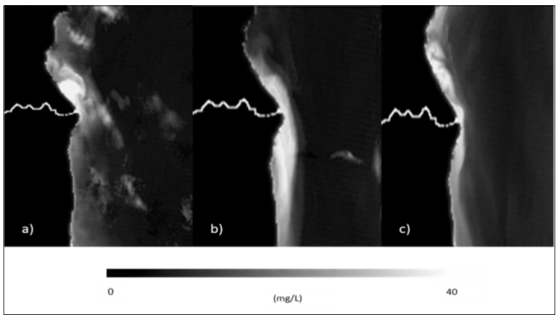


Figure 6: Images of Total Suspended Matter concentration (mg/L) derived from MODIS Terra 250 m data acquired on a) 11 September 2010, b) 26 November 2010, c) 7 October 2010 (left to right) showing significant large-scale variation in TSM following the passage of a strong front that occurred into one year of time period. Land and clouds are masked to black.

The first class refers to the main plume core, with values greater than 35 mg/l, functioning during the whole wet season. The second category (10-35mg/l) depicts the intermediate region of the plume and the near shore waters being turbid due to resuspension induced by the wave activity. The third type is the peripheral region of the plume (5-10 mg/l) while the forth class in ambient water or offshore water (< 5 mg/l). The dry season plume, being associated with low riverine water/sediment fluxes was mainly constrained close to the coast, coinciding with the near shore zone.

The inverse relationship between Chl_a and TSM shown in figure (7),where the results recorded an increase in the total suspended material (TSM) values in southwest monsoon(May, June, July, August, September) and in north monsoon (January),also in inter-monsoon (April and October), Chl-a values found opposite TSM results.

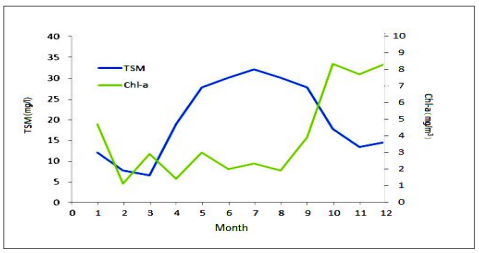


Figure7: MODIS monthly data images clarify the inverse relationship between Chl_a and TSM.

3) The Precipitation and Pahang River plume:

Figure 8 shows the relationship between time series of monthly mean precipitation (blue line) with satellite detected plume area (green line). Monthly averaged precipitation data for the region ranged between 7 and 23.9. Although net precipitation in this region follows an annual cycle, Plume river monthly rates were from 325 to 1650. Average annual precipitation maxima 1885.7 occurred from January to March. Precipitation minima 244.6 occurred during May–August and February in all years. Although the precipitation data are not perfectly phased in opposition with Pahang river plume. As expected, greater lags were found between maximum Pahang river plume and precipitation minima occurred in August. The timing of precipitation minima in the costal is also influenced by the river plume, whose maximum river plume usually occurred in December. Observed lags between river plume and precipitation are likely related to the time it takes river plume to reach the costal.

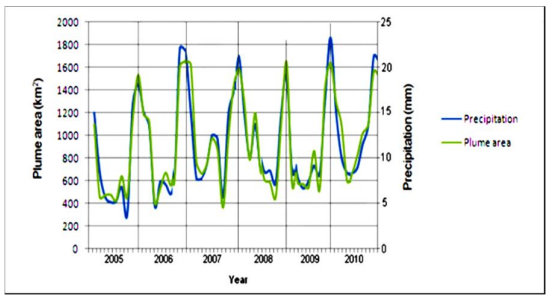


Figure8: Relationship between time series of monthly mean precipitation (blue line) with satellite detected plume area (green line).

4) Interannual variability of plume:

The spatial distributions of plume derived from n*L*w monthly composite images of MODIS sensor were high variable and sensitive to wind direction and magnitude (Figure 9**).** Wind speed data near the east coast of Pahang state, has been analyzed to determine monthly wind speed (Table2), The monthly average wind speeds ranges from 2.00 m/s in June 2005 to 5.20 m/sin January 2010, The average of wind speed during north east monsoon was 3.8 m/s, and annual mean wind speed for a 6 -year period was 2.90 m/s.

Table 2: Monthly average wind speeds and monthly average daily wind power for the period 2005-2010.

Year	2005	2006	2007	2008	2009	2010
Month	**Wind Speed (m/s)**	**Wind Speed (m/s)**	**Wind Speed (m/s)**	**Wind Speed (m/s)**	**Wind Speed (m/s)**	**Wind Speed (m/s)**
January	4.71	3.60	3.93	3.78	4.72	3.66
February	3.32	4.16	3.32	4.16	3.07	3.49
March	3.60	4.49	2.49	3.33	2.12	2.65
April	2.19	1.94	2.22	2.22	2.23	2.62
May	2.20	2.22	2.21	2.52	2.17	2.27
June	2.19	2.21	2.17	2.52	2.35	2.25
July	2.49	2.49	2.20	2.20	2.28	2.17
August	2.21	2.22	2.49	2.19	2.15	2.24
September	2.22	2.19	2.22	2.20	2.17	2.15
October	2.19	2.21	2.22	2.19	2.13	2.22
November	2.19	2.18	2.22	2.18	2.61	2.19
December	2.49	3.32	3.60	3.36	3.43	3.31

Five types of wind direction observed at the at South China Sea and along the East Coast of Peninsular Malaysia are the East Wind, Northeast Wind, West Wind, Southwest Wind, and the South Wind which could indirectly be associated with the spatial and temporal variability of Pahang River plumes (Figure 9).During the Northeast Monsoon, a strong Northeast Wind and East Wind of between 2 $ms^{-1}$to 8 ms^{-1} prevail. However the Southwest Monsoon occurring with West Wind and South Wind are dry and less than the Northeast Monsoon wind at between 1 $ms^{-1}$to 4 ms^{-1}.

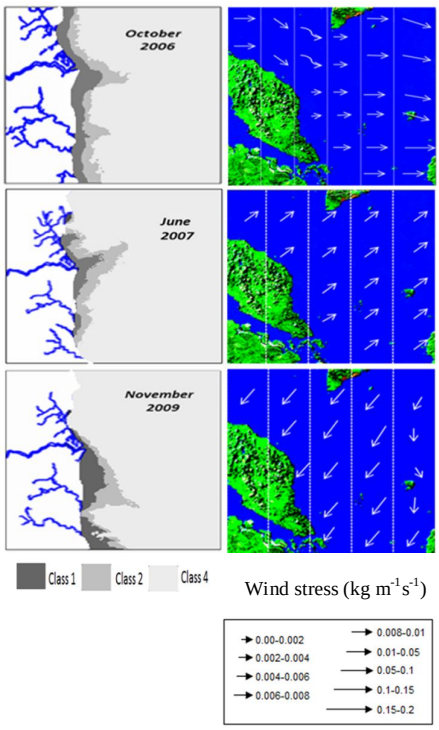
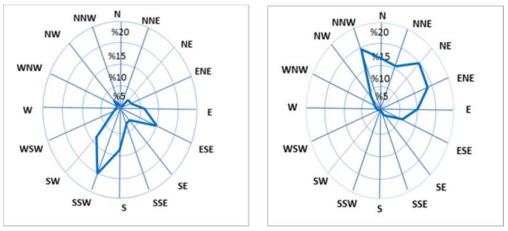
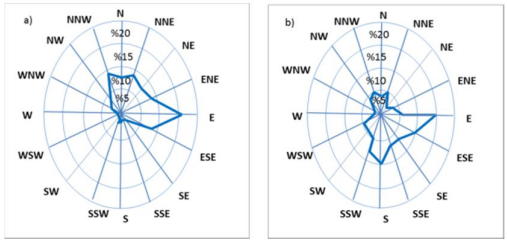


Figure 8:Influences of surface wind (right panel) on plume distribution (left panel). A) west-east wind pushed the plume to offshore. B) Southwest wind pushed the plume to northeast. C) Northeast wind pushed the plume to southeast.



The southwest monsoon period (May to September)

The northeast monsoon period (November to March)



The inter- monsoon period (April and October) (a, b)

Figure 9: The wind roses and summary of wind directions over the past 6 years (2005-2010).

4) Empirical orthogonal function (EOF):

The overall temporal variability of the plume in the complete time series is effectively summarized using an empirical orthogonal function (EOF) decomposition of the 6-year monthly image sequence of nLw 551. An EOF decomposes a time- and space-varying signal. Each mode is represented by a space pattern and a time series describing the modulation of that pattern over the study period and percentage of spatial variation of EOF to the Pahang River Plume **(**Figure 10 and figure 11**).**

A) The space pattern associated in mode 1with variance of 75.3% shows a maximum offshore of the river mouth, extending in an alongshore pattern approximatelymean5 m isobaths of the river mouth, in the inter-monsoon.

The time series shows are high signal levels .There were low in the inter- monsoon of 2005, 2006, 2008 and 2010.Low negative signal of temporal amplitude was in inter monsoon (October 2006, 2010).

B) Second mode of nLw551 EOF analysis indicated that the space pattern associated with mode 2 with variance of 6.4% shows negative signal of temporal amplitude occurred in the southwest monsoon (September 2007, June and August 2005, May 2006 and August 2006, 2007 and 2008).Southwest monsoon of 2007.

C) Third mode of nLw551 EOF analysis, space pattern associated with mode 3 with variance of 3.2% shows positive signal was in the northeast monsoon during (November 2005, 2006, 2010 March 2008, 2009) .

D) The forth mode explains about 8.7% variance in the spatial and temporal variability. Positive signal indicates the movement of the plumes tends to propagate offshore and northward during Southwest Monsoon. Meanwhile negative signal exhibits the pattern of plumes settling down of plume at the south of coastal area. The positive amplitude signal can be observed in May, June 2006 , July 2007 and 2008; August 2008 and 2009.

Time series explain monthly mean wind stress for all seasons from 2005-2010 (figure10)The plume signature was identified using the nLw (551) value strong positive amplitude signals were characterized by high nLw (551) values (figure11),Meanwhile strong negative amplitude signals were characterized by low nLw (551) values . The strong plume signature was observed in northeast monsoon (wet season) 2006 with nLw 551 values exceeding 3.0 (m W $cm^{-2}\mu m^{-1}$ sr^{-1})(figure 3) ,while in late northeast monsoon of 2005 and southwest monsoon of 2007 nLw (551) values exceeded 2.5(m W cm^{-2} μm^{-1} sr^{-1}), while in northeast monsoon of 2010 nLw (551) values less than 1.8,in late northeast monsoon 2008 <1.0(m W cm^{-2} μm^{-1} sr^{-1}), southwest monsoon (dry season)2006<2.0 (m W cm^{-2} μm^{-1} sr^{-1})and early(April) in inter monsoon <1.5(m W cm^{-2} μm^{-1} sr^{-1}).

The time series associated with seasonal pattern is maximum in Northeast monsoon and minimum in Southwest monsoon every year. Time series are high in the inter-monsoon of 2005, 2006, 2008 and2010.

The high negative signal of temporal amplitude occurred in the Southwest monsoon during September 2007, June and August 2005, May 2006 and August 2006, 2008, 2010, also high negative signal occurred in the Northeast monsoon during February 2005, 2007, 2008.The high positive signal in the Northeast monsoon were during January2005, 2006, 2010 November 2007, 2008 December 2006, 2009, 2010andduring the Southwest monsoon showed in August 2006, September 2008, 2010, July2007.

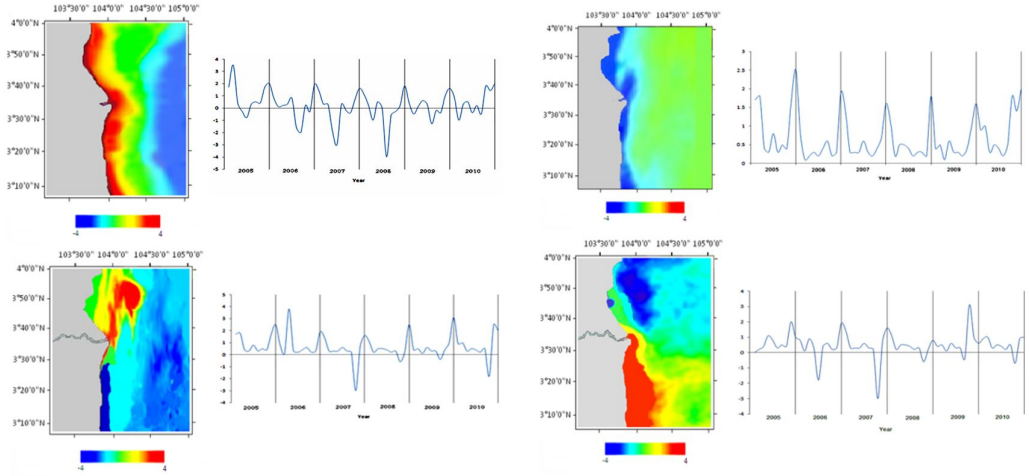


Fig 10) Results of the EOF decomposition of 6-year monthly time series of nLw 551.(a) first mode showing high positive signal (b) second mode is high negative signal , (c) third mode is positive & low signal (d) forth mode is positive & negative signal. Each mode consists of a space pattern is left and the time pattern (time series) is right, which together explain 93.6% of total variance.

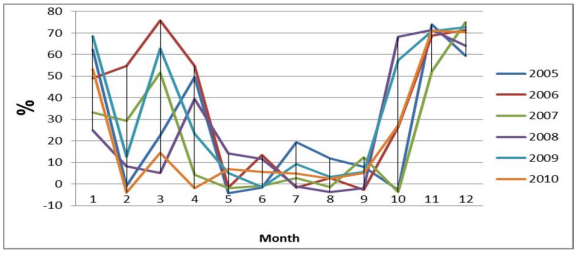


Fig 11) Percentage of spatial variation of EOF during Pahang River Plume

DISCUSSION

The chlorophyll-a content in the east coast of Peninsular Malaysia is generally low, ranging from 0.08 (surface) to 0.36 mg/m^3 , however, inter-monsoon period between southwest and northeast monsoon (April to early May & late September to October) suggests the lowest chlorophyll concentration value of 0.2 mg/m^3 as compared to other monsoon periods. The wind roses (Figure9) explain the direction of winds during two monsoons in Malaysia for 6 years and the percentage of wind speed. Comparison of the mean wind of December and August indicated it that winds speed during the SW monsoon season is less value than its NE. At the same time, the current flow direction is also inferior in August. The behavior of the current flow correspond to the period of the SW monsoon season is quite similar, flowing northwards along east coast of Peninsular Malaysia (Nasir, M.S, et al ,1997). However, the bulk of the water mass, due to the combined effects of bottom topography and wind stress, will eventually flow towards the east coast of Peninsular Malaysia. In the same case as for the NE monsoon, the current flow along the Peninsular Malaysia's east coast is slightly greater than the SW monsoon (May and September), these two pressure systems strengthen a southwesterly wind over the study region. This system is known as the southwest monsoon wind with cloudless skies over the eastern coast of Peninsular Malaysia are observed during this period, (Alejandro et al, 1997).

Two transitional periods (usually occurring during the months of April and October were observed between these two monsoon seasons. These transitional periods, usually last for a period ranging from four to seven weeks (Thomas. A, et al 2006). Heavy rainfall in the east coast of the Peninsular Malaysia, is usually associated with the northeast monsoon. The east coast is considered the wet belt of Peninsular Malaysia, with an annual rainfall of 2800 mm. Maximum precipitation usually occurs during the months of November and December (Chua, 1984). Heavy precipitation and freshwater discharge from rivers, due to extreme rainfall, are one of the main characteristics of the NE monsoon season, The NE monsoon winds is stronger than the SW monsoon winds, (Taira et al. 1996).The pattern distribution of this high TSM during wetseason seemed to follow the tongue-like shallow bathymetric (1-5 km) feature indicating that the prevailing strong northeast winds re-suspended shallow bottom sediment, resulting in high TSM during wet season. The tongue-like high TSM pattern disappeared in dry season associated with the less sediment re-suspension due to the weak southwesterly wind during dry season.

Conclusion

The plume extends south during the NE monsoon under the influence of northward wind stress, closest to the river mouth during periods of maximum wind forcing. During the SW monsoon, the plume extends north, under the influence of dominant southward winds. The plume extends in the antimonsoon under the influence of west-east & south west winds stress, and it is usually along the coast. Interannual differences in the plume pattern evident in satellite data are strongly related to differences in wind currents .The results showed high variability spatially and temporally of EOF analysis during the NE monsoon, Interannual differences associated with wind forcing are most clearly evident during the NE monsoon , when are storm events are strongest throughout the region. Wind stress and its effect on circulation is strongest in NE monsoon. The variability of the plume pattern was demonstrated by EOF analysis. As for our future work, the changes in timing of the seasonal cycles need further study. The correlations between TSM and Chl-a are difficult to evaluate owing to a loss of residual quasi-annual signals in each record (Figure 6), caused by a change in the timing of the seasonal cycles. Visually, the time series appear correlated on several timescales, not just quasi-annual. Our results show that the time series is well suited to extracting numerous metrics of relative interannual variability in plume size, position and signature relevant to fisheries and coastal management. Future efforts to collect data will result in a quantitative assessment of plume dynamics in biogeochemical units, further increasing the utility of satellite multispectral data in monitoring the position, strength and character of the Pahang River plume and increasing their value as a local ecological monitoring tool.

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