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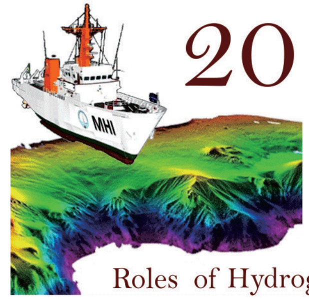

2013

Batam Island, 27-29 August 2013

International Seminar .and Workshop on Hydrography

Roles of Hydrography in Marine Industry and Resources Management

Seminar Proceeding

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THE SPATIO TEMPORAL DYNAMIC OF DIFFUSE ATTENUATION COEFFICIENT IN THE TROPICAL BERAU ESTUARY, EAST KALIMANTAN INDONESIA

Wiwin Ambarwulan
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ABSTRACT

The availability of light in the water column determines the euphotic zone and constrains the type and the vertical distribution of benthic species. Diffuse attenuation coefficient (*K_d*)is an important apparent optical property (AOP) that provide information about the attenuation of the spectral downwelling solar irradiance with depth in the water. Ocean color Satellite provide global coverage of optical water quality parameters at spatial and temporal resolution. Several empirical and semi-analytical models are commonly used to derive *K_d* at wavelength 490 nm *$K_d(490)$* from ocean colour satellite sensors. This study present about the diffuse attenuation coefficient, *$K_d(490)$* using semi-analytical approach. The dynamic *$K_d(490)$* in the Berau Estuary water was studied and compared with those derived from ocean color satellite sensor, Medium Resolution Imaging Spectrometer (MERIS). The study indicated that *$K_d(490)$* of *in situ* measurement had the best correlation with the *$K_d(490)$* of MERIS data of remote sensing reflectance (*R_{rs}*) derived with FUB (Free University Berlin) algorithm (R^2=0,84). The dynamic of *$K_d(490)$* from MERIS data on different date indicated that the *$K_d(490)$* have a similar pattern and decreased when going to offshore.

Key words: MERIS, Secchi disc depth, tropical coastal water, $K_d(490)$, a semi-analytical approach

I. INTRODUCTION

Monitoring the coastal and marine waters is a subject of many countries' attention, including Indonesia which has more than 13.466 islands which encompass 75% (6,1 Millions km^2) of coastal and marine area. The country compose of a complicated geography with a great number of islands, narrow straits, large river estuaries, strong variations in bathymetry and mainly, a vast and large geographic area. For the Indonesian case, it is difficult to monitor the large coastal zone with only *in situ* observations. Facing to this problem, remote sensing methods give a practical solution as an effective tool for investigating and monitoring Indonesian waters. Remote sensing approaches applied to series of satellite images can provide information on a large area, showing the spatial and temporal development of sea surface features induced by various dynamic processes. Remote sensing reflectance is an important tools for characterizing the coastal and oceanic optical environment. The oceanic and coastal processes alter the optical properties of waters and these effects get manifested in the colour of the water. Remote sensing provides an extremely valuable tool for rapidly assessing the spatial variability of coastal and oceanic water reflectance patterns. Satellite based ocean colour sensors have been used to map biological and optical properties of the ocean on local and global scales.

The current operational algorithms for various ocean color satellites, including atmospheric corrections and bio-optical algorithms, produce large error in the tropical equatorial water. One of the problems in remote sensing of the tropical environment is the improvement of accuracy, related to water properties. As has been known, one of the keys to improve the accuracy of estimation of the seawater constituents from ocean color remote sensing is a better understanding of coastal bio-optical properties. In-water optical properties are classified into two main types: inherent optical properties (IOP) and apparent optical properties (AOP) (Preisendorfer, 1976). Until recently, most of the bio-optical properties of the coastal and marine water have been acquired mainly at higher to mid-latitudes coastal water. Only limited study of bio-optical model have been done in equatorial tropical country. The study of bio-optical properties in Indonesian water from MERIS data was done by Ambarwulan (2002, 2010), Ambarwulan *at al.* (2010, 2011, 2012).

The spectral diffuse attenuation coefficient $K_d(\lambda)$ is one of the most important apparent optical property (AOP) of seawater (Preisendorfer, 1976). It is directly linked to the IOPs such as absorption and backscattering properties (Gordon, 1989; Lee *et al.*, 2005). K_d is an indicator of water clarity and water quality and it is also indicator how strong light at a particular wavelength is attenuated within the water column. It plays a very critical role to understand the absorption and backscattering properties, photosynthesis and primary productivity models (Sathyendranath, 1989), biological processes in the water column, and to classify water types (Jerlov, 1976). Thus K_d is an important parameter for remote sensing of ocean color. Some researches have been shown that Kd can be estimated reliably from remote sensing data in the Baltic Sea (Darecki & Stramski, 2004; Kratzer *et al.*, 2008).

At present, three operational standard algorithms are used for deriving of K_d in ocean color remote sensing (Lee *at al.*, 2005). Method 1, Direct One-Step Empirical Relationship for K_d (490) was developed by Austin and Petzold (1986). K_d is estimated from an empirical algorithm based on the relationship between K_d (490) and the blue-to-green ratio of water-leaving radiance, *Lw*, or remote sensing reflectance, R_{rs} (Mueller, 2000). Method 2, Two-Step Empirical Algorithm use Chl as an intermediate link. A commonly applied approach is first, deriving chlorophyll-a concentration, Chl, from remote sensing reflectance using the empirical algorithm (O'Reilly *et al.*, 1998), and then deriving K_d (λ) from Chl using another set of empirical relationships (Morel, 1988; Morel and Maritorena, 2001). Method 3 is a Semi-analytical Approach. The method involves the concept that the apparent optical properties (AOP) and the inherent optical properties (IOP) of seawater and boundary conditions (such as solar zenith angle and sea state) through radiative transfer theory.

The objective of this study was to retrive K_d from *in situ* and MERIS data using the semi-analytical approach.

II. METHODOLOGY

2.1 The Study Area Description

The Berau Estuary is located in Berau Regency, the East Kalimantan Province, Indonesia. Geographically, the Berau delta and its estuaries are located between 01º45' to 02º35' N and 117º20' to 118º45' E (Figure 1). The Berau Estuary is very unique environment with a range of shallow marine environments from turbid coastal estuarine to open oceanic and shelf edge reef conditions. The estuary is very rich marine biodiversity in Indonesia such as the mangrove system in the delta, the coral reef in the oceanic and seagrass aorund the Derawan Islands. The coral reef system in the Derawan Islands is famous as one of the best diving spot in Indonesia and is locatef around 40 km from the mouth aof the Berau River. Monitoring the water quality of this complex estuary system is very challenging in the context of developing future plans to protect the coral reef life in this area against increasing sediment flux from the Berau River.

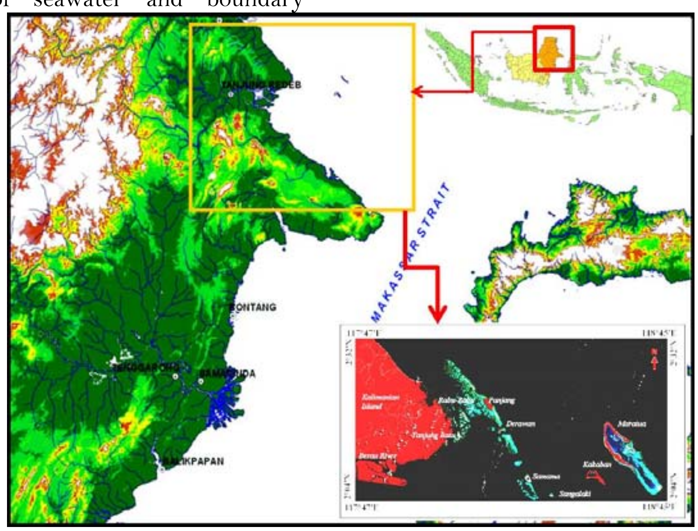

Figure 1. Study Area: The Berau Estuary, East Kalimantan, Indonesia

2.2. Data Set

a. Radiometric Measurement

The optical measurement was done in the Berau water in the periode of August - September 2007. An Ocean Optic spectrometer (USB4000) was used to collect *in situ* spectral measurements, following the REVAMP measurement protocols (Tilstone *et al.*, 2004). The paramters of the optical measurement collected in this study area, the water leaving radiance, the downward skylight irradiance and subsurface upwelling irradiances were scanned at each station at different under water depths (10, 30 and 50 cm). Totally, 33 stations were measured in the Berau coastal water and nearby region. From those total field station observed, only 8 stations were match up with the

MERIS data with low cloud present in the imagery.

b. Physical and biological variables

Bio-geophysical variables were measured in the field using digital water checker, Horiba U10, secchi disk depth and a Turner fluorescent spectrometer. The variables were measured in the same location as the optical data. The water samples were collected at depths between 20 and 50 cm, stored at a dark place at 5°C, and were analyzed immediately after arrival on the base camp on Derawan Island. The Total Suspended Matter (TSM) concentration was measured after filtering samples through a 47 mm diameter Whatman GF/F glass fiber filter with pore size of 0.45 µm, based on REVAMP protocols (Tilstone *et al.*, 2004). The Chl *a* concentration was measured using a Turner fluorescence spectrometer. Other generic water quality variables (conductivity, temperature, pH, turbidity, dissolved oxygen and salinity) were measured using a Horiba U10 water quality multi-sensor probe. The Secchi disc depth and water depth was measured at each location using a Secchi disc (diameter 20 cm) and a GPS-coupled Garmin echo depth sounder, respectively.

c. Remotely sensed Imagery

Medium Resolution Imaging Spectrometer (MERIS), a remotely sensed imagery was used in this study. MERS Level 1b (L1b) and Level 2 (L2), provided by the European Space Agency (ESA) were used. In the period of 2003 until 2007, there are 20 MERIS L1b and L2 data sets at Reduced Resolution (RR) and Full Resolution (FR) available for this study area. However, not all the MERIS data were used in this study because of cloud present on this equatorial region, so the number of appropriate imges become quite limited. From the available images, only three images were coincident with *in situ* measurements: August, 28 and 31, 2007 and September 15, 2007.

2.3 Methods and Algorithms

Three major processing steps have been carried out in order to estimate the K_d from MERIS data: (1) the estimation of R_{rs} from the *in situ* and MERIS data set, (2) the calculation K_d using the semi-analytical approach.

1. Estimation Remote Sensing Reflectance (Rrs)

The Rs of *in situ* optical measurement obtained with the Ocean Optic spectrometer which was the subsurface irradiance reflectance $R(\lambda,0^-)$ at each wavelength (λ) was calculated. The Subsurface irradiance reflectance, $R(0-)$ is one of AOP parameters and is given by (Mobley, 1994) as the ratio of upward (E_u) and downward (E_d) irradiance (µWcm^{-2}nm^{-1}) just beneath the water surface:

$$R(\lambda,0^-) = \frac{E_u(\lambda,0^-)}{E_d(\lambda,0^-)}$$

The subsurface remote sensing reflectance was calculated using:

$$R_{rs}(0^-) = \frac{R(0^-)}{Q} \tag{2}$$

where Q stands for the geometric anisotropy factor of the underwater light field, usually taken as Q = 5 sr (Gege 2005). From the subsurface remote sensing reflectance, the above surface remote sensing reflectance was calculated using (*see* e.g. Bhatti *et.al*, 2009):

$$R_{rs}(0^+) = 0.544 * R_{rs}(0^-) \tag{3}$$

The R_{rs} of MERIS data was derived with different atmospheric correction methods. Those algorithms are the ones that are plugged-in on BEAM Visat: the C2R algorithm and FUB. These deliver various output products. However, in this study focus will be on the remote sensing reflectance (product from C2R, FUB and MERIS L2.

2. Retrieval diffuse attenuation coefficients (Kd) using A Semi-analytical Approach

This study used the Method 3, the semi-analytical approach . The essence of this method is that K_d can be calculated based on the QAA and equation (4) when the values of R_{rs} (λ) are known. Lee *et al* (2005) described that the IOP parameters such as the values of the absorption, *a*, and backscattering, b_b, coefficients are most essential to the determination of both apparent optical properties, R_{rs} and K_d. When the values of *a* and b_b are known, along with boundary conditions, R_{rs} and K_d can be calculated using the semi-analytical models (Lee *et al.*, 2004, 2005). In general the Method 3 is divided into 2 steps. The first step was calculated *a* and b_b paramters using a Quasi-Analytical Algorithm (QAA). The input of this step were R_{rs} of *in situ* measurement and R_{rs} of MERIS data. The second step was calculated Kd by using the formula established by Lee *et al.* (2005):

$$K_d = m_0 a + m_1(1-m_2 e^{-m_3 a})b_b \tag{4}$$

where $m_0 \approx 1 + 0.005\theta_a$ and θ_a is the solar zenith angle in air. The values for model constants m_1, m_2, and m_3 are 4.18, 0.52, and 10.8, respectively

(Lee *et al.*, 2005). These values remain constant for different waters and different wavelengths.

III. RESULTS AND DISCUSSIONS

3.1 Remote Sensing Reflectance

The magnitude and spectral variation of remote sensing reflectance (R_{rs}) depend on the IOPs i.e. absorption and backscattering properties of seawater itself, phytoplankton, Colour Dissolved Organic Matter (CDOM) and detritus. The R_{rs} of the Berau Estuary waters have been studied by Ambarwulan *et al.* (2010). There were 9 stations with remote sensing reflectance data measured by the Ocean Optic USB4000 which matched up with MERIS L1 of 31 August 2007. The spectra retrieved by applying the different algorithms on the MERIS L1 image data showed different shapes and magnitude of remote sensing reflectance, R_{rs}. The Remote sensing reflectance of *in situ* measurement, R_{rs} of MERIS data using C2R, FUB and MERIS L2 algorithm are displayed on Figure 2.

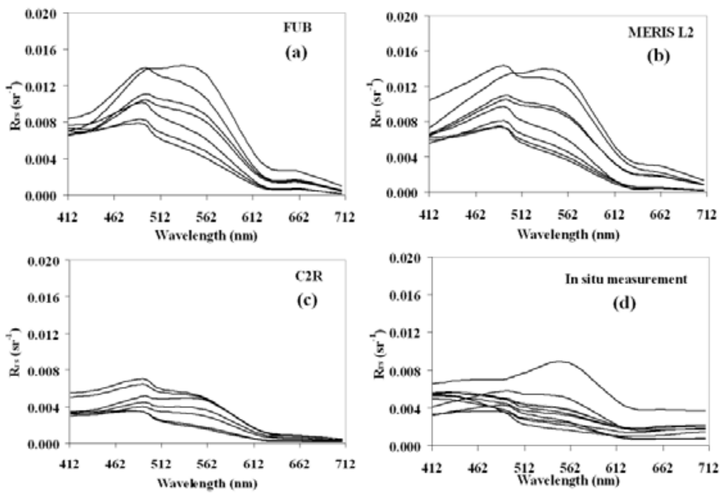

Figure 2. The R_{rs} of *in situ* measurement and R_{rs} of MERIS data derived from different algorithm (Ambarwulan *et al.*, 2010)

3.2 Diffuse Attenuation Coefficient(K_d) Using Direct One-Step Empirical Approach

The diffuse attenuation coefficient (K_d) of the Berau Estuary waters was studied by Ambarwulan *et al.* (2010) from MERIS data and *in situ* measurements. The method for retrieving K_d was based on an empirical approach following the work of Kratzer (2008). The K_d measured and R_{rs} measured in the field on 31 August 2007 were used to establish the relationship between K_d and R_{rs} measured. The best fit between R_{rs} measured and K_d measured was achieved with the ratio R_{rs} at 490 and 620 nm (R2= 0.76) for the Berau Estuary waters is:

$$\ln(K_d\,(490) - K_{dw}) = 0.49 * \ln(R_{rs}490 / R_{rs}\,620) + 0.028.$$

The research found that the best $K_d(490)$ model have a similar pattern which was high in the location close to the Berau river mouth and decreases towards the open sea. The best model between K_d (490) and distance was exponential, with R^2 were 0.61; 0.67 and 0.77 for C2R, MERIS L2 and FUB respectively.

3.3 Diffuse Attenuation Coefficient Using the Semi-analytical Approach

For this study, the R_{rs} of *in situ* measurements have been calculated using Eq. (1) to Eq. (3). Whereas, the R_{rs} from MERIS data were derived by applying global algorithm of MERIS L2, C2R and FUB algorithms using the BEAM software. The MERIS L2 and C2R water leaving radiance reflectance (R_w) were converted to R_{rs}. The best correlation between R_{rs} *in situ* meausrement and R_{rs} MERIS data was analyzed based on the degree of coefficient of determination (R^2) were 0.72, 0.63 and 0.59 for C2R, FUB and MERIS L2 respectively.

The R_{rs} of *in situ* measurement of the Berau Estuary waters was an input on the QAA as well as R_{rs} of MERIS data derived with different algorithms. The absorption, *a*, and backscattering, b_b, coefficient derived from QAA were used as the input of the K_d algoithms. The diffuse attenuation coefficient of *in situ* measurements and MERIS data at wavelength 490 nm ($K_d(490)$) in the Berau Estuary waters was derived by using Eq. (4). The $K_d(490)$ derived from *in situ* measurement as well as MERIS data displayed in Table 1 and Figure (3a).

Table 1. The magnitude of $K_d(490)$ derived by the semi-analytical approach from *in situ* measurement and MERIS data

	INSITU	FUB	C2R	L2
Minimum	0,080	0,077	0,071	0,107
Maximum	0,328	0,218	0,265	0,459
Mean	0,139	0,121	0,133	0,219

Table 1 showed that the magnitude of the $K_d(490)$ in this study was the highest in one derived from R_{rs} reflectance of MERIS data using MERIS L2 global algorithm and the lowest one was derived from R_{rs} of MERIS data using FUB algorithm. The Figure (3a) showed that $K_d(490)$ of *in situ* measurement and $K_d(490)$ derived from MERIS data using C2R, FUB and MERIS L2 have the similar trend which is low in the clear water staions (31-2, 31-3, 31-8 and 31-9), and higher in the more turbid water station (31-6). This was due to the fact that the station 31-6 was located on the turbid water and decrease the turbidity on the station 31-5, 31-3, and 31-7. Hence, the station 31-2, 31-3, 31,8 and 31-9 were located in the clear waters. The result shows that the higher $K_d(490)$ were found around the river mouth of the Berau River and decrease to the open sea.

The best fit between $K_d(490)$ measured *in situ* and $K_d(490)$ derived from MERIS data was obtained based on the highest R^2 and the lowest RMSE. The study found that the best fit correlation between $K_d(490)$ measured *in situ and* $K_d(490)$ derived from MERIS data with R_{rs} of FUB algorithm (R^2=0,84) and followed by R_{rs} of MERIS L2 (R^2=0,81) and R_{rs} of C2R (R^2=0,76). In order to evaluate the performance of the $K_d(490)$ retrieval using the semi-analytical approach, the Root Mean Square Error (RMSE) was calculated. The RMSE $K_d(490)$ of FUB is lower than C2R and MERIS L2 especially in the clear water. However in the turbid water the RMSE of C2R was lower compare to FUB and MERIS L2. In this case,we may conclude that the atmospheric correction is responsible for the different results.

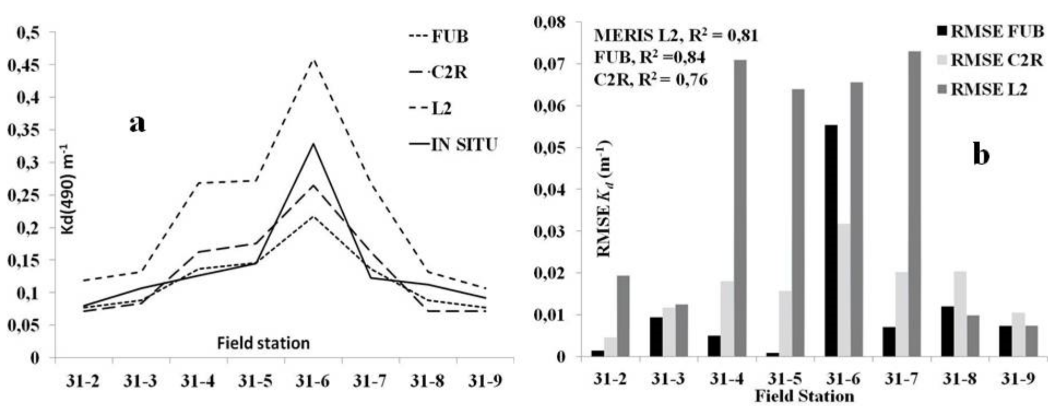

Figure 3. The $K_d(490)$ of the Berau Estiary waters from in situ measurement and MERIS data (left, a) and the RMSE and R2 of $K_d(490)$ (right, b)

3.4 Spatial Temporal Dynamic of Diffuse Attenuation Coefficient

In order to understand the spatial and temporal dynamics of $K_d(490)$ in the Berau Estuary, the $K_d(490)$ was estimated from MERIS data recorded, such as 28 August 2007, 31 August 2007 and 15 September 2007. Figures 4a, 4b and 4c illustrate the estimated $K_d(490)$ for the Berau Estuary waters from reduced resolution MERIS data. The 1200 m resolution of MERIS data reveals the spatial distribution of $K_d(490)$ throughout the study area. These $K_d(490)$ gradients are particularly evident in the middle portion of the image where the Berau River flows into the estuary. It shows clearly that $K_d(490)$ is higher around the coastal area and decrease when going to the sea.

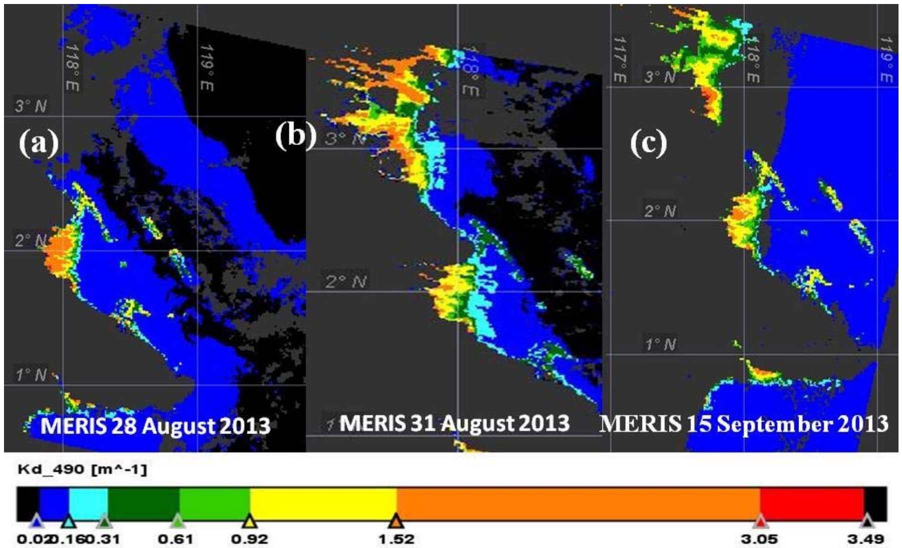

Figure 4. The $K_d(490)$ from MERIS data at 28 and 31 August 2007 and 15 September 2007

The spatio and temporal dynamic were also discussed by using three samples or pin points representing different water turbidity levels which were selected. These pin points spread out from shallow and turbid water close to the Berau river mouth into the inner shelve and lastly in the outer shelve. The analysis of $K_d(490)$ at the 3 pin points is displayed in Figure 5. Similar patterns of $K_d(490)$ occurred for turbid, medium turbid and clear water with Secchi disk depths of 0,8 meter, 4 meter and 10 meter respectively. In general the $K_d(490)$ dereived using C2R was robust for the medium to clear water, however over estimation on the turbid water. This case can be explained due to the IOP used in the C2R was the IOP of the high latitude water such as European coastal waters.

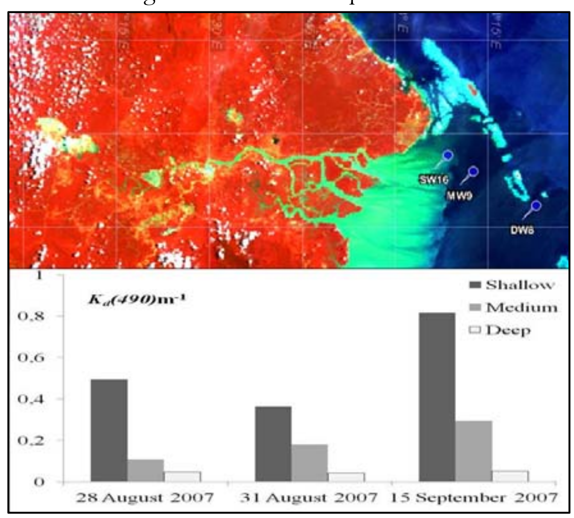

Figure 5. The spatio and temporal dynamic of $K_d(490)$ in the Berau Estuary waters

IV. CONCLUSIONS

From the results obtained, it can be concluded that in this equatorial coastal zone, the MERIS RR data permit to derive optical water properties such as diffuse attenuation coefficient ($K_d(490)$) with a reasonable accuracy. The semi-analytical approach that involves the concept that the apparent optical properties (AOP) and the inherent optical properties (IOP) of seawater give a better result on estimating $K_d(490)$ from MERIS data. The $K_d(490)$ with remote sensing reflectance derived with FUB, C2R and MERIS L2 give a good correlation with $K_d(490)$ derived with *Rrs* of in situ measurement and its proved with the quite highr R^2 and less RMSE. The $K_d(490)$ derived with FUB was the low RMSE and high R^2.

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