

# Monitoring tropical coastal waters of Berau estuary, East Kalimantan, Indonesia using MERIS data

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**Abstract** – This paper investigates the performance of MERIS reduced resolution data to monitor water quality parameters in the Berau estuary waters, Indonesia. Total Suspended Matter (TSM) and Chlorophyll-a (Chl-*a*) concentration were derived from MERIS data using three different algorithms for coastal waters: standard global processor (MERIS L2), C2R and FUB. The outcomes were compared to *in situ* measurements collected in 2007. MERIS data processed with C2R gave the best retrieval of Chl-*a*, while MERIS L2 performed the best for TSM retrieval, but large deviations from *in situ* data were observed, pointing at inversion problems over these tropical waters for all standard processors. Nevertheless, MERIS can be of use for monitoring equatorial coastal waters like the Berau estuary and reef system.

**Keywords:** water quality, ocean colour, TSM, MERIS, Chlorophyll-*a*, remote sensing reflectance

## 1. INTRODUCTION

A Medium Resolution Imaging Spectrometer (MERIS) was launched by European Space Agency (ESA) in 2002, mounted on the ENVISAT satellite platform. The spatial resolution is 1.2 km at nadir in the Reduced Resolution (RR) mode. This configuration provides at present one of the best capabilities for observing the optically complex coastal or Case-2 waters. Since its launch, several studies have been focussed on retrieval of water quality parameters in coastal marine waters, such as on total suspended matter (TSM), chlorophyll *a* (Chl-*a*) concentrations and Colour Dissolved Organic Matter (CDOM) retrievals (Alikas and Reinart, 2008; Aiken *et al.* 2007; Doerffer and Schiller, 2007; Schroeder *et al.* 2007).

Among the algorithms used for retrieving TSM and Chl-*a*, the Case-2 Regional (C2R) developed by Doerffer and Schiller (2007) and the Free University Berlin (FUB) water, developed by Schroeder and Schaale (2005) have been especially developed for Case-2 waters and those algorithms are plug-in on the Beam Visat software. Most of the algorithm development for estimating water quality parameters from MERIS data has been carried out in European coastal waters, mainly at mid-latitude. Limited research has been carried out in the tropical equatorial region, especially in Indonesian waters. The aim of this study is to analyze the performance of MERIS Case-2 water products and their applicability for monitoring the Berau coastal waters.

## 2. METHODS

### 2.1. The study area description

The Berau estuary is situated in the Berau Regency of East Kalimantan Province, Indonesia and is located between 01°45' to 02°35' North and 117°20' to 118°45' East (see Figure 1). The Berau barrier reef is a large flourishing front-barrier reef with numerous patches and platform reefs such as Derawan Island that is located around 40 km from the Berau river mouth.

### 2.2. In situ data

A field campaign was carried out on August and September 2007. In total, 18 transects were measured and consisting of 171 field stations. The distribution of the stations is shown in Figure 1. From all the stations, only one day of the field campaign (9 stations) gave a match-up with non-clouded MERIS products. The field campaign of 31 August 2007 was used in this study.

An Ocean Optic spectrometer (USB4000) was used to collect *in situ* spectral measurements, following the REVAMP measurement protocols (Tilstone *et al.* 2004). The water leaving radiance, the downward skylight irradiance and subsurface upwelling irradiances were scanned in each station at different depths (10, 30 and 50 cm), providing a more robust remote sensing reflectance,  $R_{rs}$  spectrum. The TSM concentration was measured based on REVAMP protocols (Tilstone *et al.* 2004). The Chl-*a* concentration was measured using a Turner fluorescence spectrometer. The Secchi disc depth and water depth was measured using a Secchi disc (diameter 20 cm).

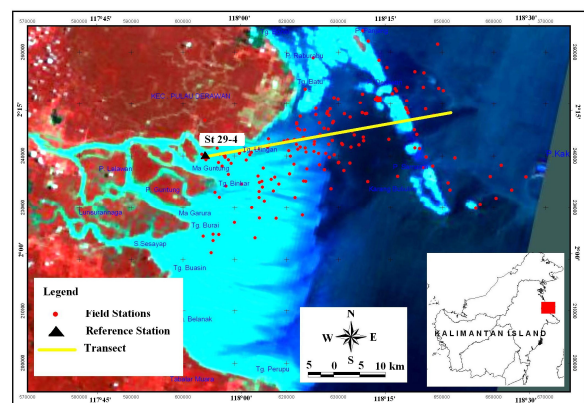


Figure 1. The location of field stations in the Berau estuary, East Kalimantan Indonesia, plotted on the MERIS FR L1 image, recorded on 17 May 2007.

### 2.3. Models and algorithms

The MERIS RR L1b and L2 images of 31 August 2007 were analyzed. L2 is processed by the ESA ground segment processor. The Basic ENVISAT Toolbox for MERIS BEAM version 4.5.1 was used for processing the MERIS L1 data. The

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MERIS RR L1b TOA radiances were processed into L2 with two regional Case-2 water processors, C2R and FUB processor.

From *in situ* optical measurements, the subsurface irradiance reflectance  $R(\lambda, \theta^-)$  at each wavelength ( $\lambda$ ) was calculated. The  $R(\lambda, \theta^-)$  is given by (Mobley, 1994) as the ratio of upward ( $E_u$ ) and downward ( $E_d$ ) irradiance ( $\mu\text{Wcm}^{-2}\text{nm}^{-1}$ ) just beneath the water surface:

$$R(\lambda, \theta^-) = \frac{E_u(\lambda, \theta^-)}{E_d(\lambda, \theta^-)} \dots (1)$$

The subsurface remote sensing reflectance was calculated using:

$$R_{rs}(\theta^-) = \frac{R(\theta^-)}{Q} \dots (2)$$

where  $Q$  stands for the geometric anisotropy factor of the under water light field, usually taken as  $Q = 5$  sr (Albert and Mobley, 2003; Gege 2005).

### 3. RESULTS

#### 3.1. Water quality dynamics

The Berau estuary belongs to the category of Case-2 waters that are characterized by presence of relatively high quantities of TSM and CDOM. The CDOM absorption in the Berau estuary ranged from  $1.67 \text{ m}^{-1}$  in the river to  $0.091 \text{ m}^{-1}$  in clear waters. Around the Berau river mouth, CDOM absorption value was  $0.5 \text{ m}^{-1}$ . We note that the lowest CDOM measured was still higher than the threshold for Case-2 waters (Kratzer *et al.* 2008).

The TSM concentration measured in the field varied with the average value of  $21.42 \text{ mg l}^{-1}$ . In order to better understand the spatial and temporal distribution of TSM concentration in the Berau estuary, the TSM concentration measured *in situ* is plotted against the distance to the Berau river mouth (latitude-longitude:  $117^\circ 56' 15.9 \text{ E } 02^\circ ; 10' 16.8 \text{ N}$ , indicated with a station 29-4 in Figure 1) as a starting point. The result shows that there is a large temporal variability of TSM in this period and no unique relation exists between TSM concentration measured *in situ* and the distance.

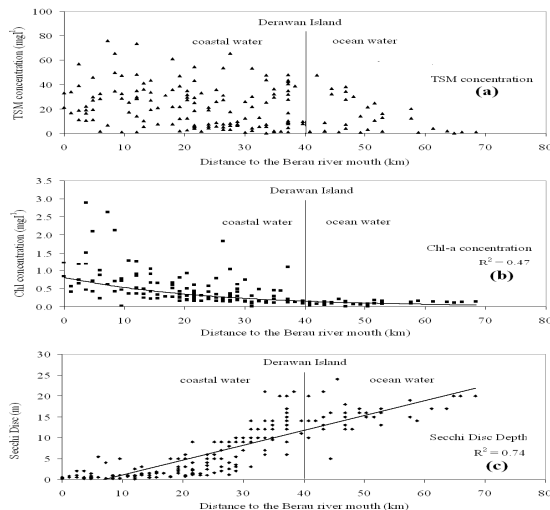


Figure 2. The *in situ* observation of TSM concentration (a), Chl-*a* concentration (b) and Secchi disc depth (c) plotted as function of the radial distance from the Berau river mouth.

The pattern of Chl-*a* concentration measured *in situ* seems more correlated with the distance (Figure 2b). The distribution trend of Chl-*a* concentrations against the distance favor an exponential model with  $R^2 = 0.47$  ( $n=171$ ). For the Secchi-disc

depth (SD), low SD values (1-2 m) were found close to the river mouth and increased to 15 m or more in offshore direction (Figure 2c). A simple linear regression model gave a best fit, with  $R^2 = 0.74$  with  $n=171$ .

#### 3.2. MERIS water quality maps

The distribution of TSM concentration and Chl-*a* concentration derived from MERIS RR data of 31 August 2007 using the C2R, FUB processor algorithm and MERIS L2 are displayed in Figure 3. All images show high TSM concentrations in the location close to river discharge and tend to decrease offshore. The TSM concentration derived with C2R processor algorithm (Figure 3a) was higher than ones derived with FUB and MERIS L2 (Figure 3b and Figure 3c). For Chl-*a*, the concentration derived with FUB (Figure 3d) was higher than C2R and MERIS L2 (Figure 3e and Figure 3f). These patterns appear more clearly when they were plotted along the same transect, as is shown in Figure 4. The highest difference between the three algorithms occurred in the most turbid water, located at a distance between 0 km and 20 km.

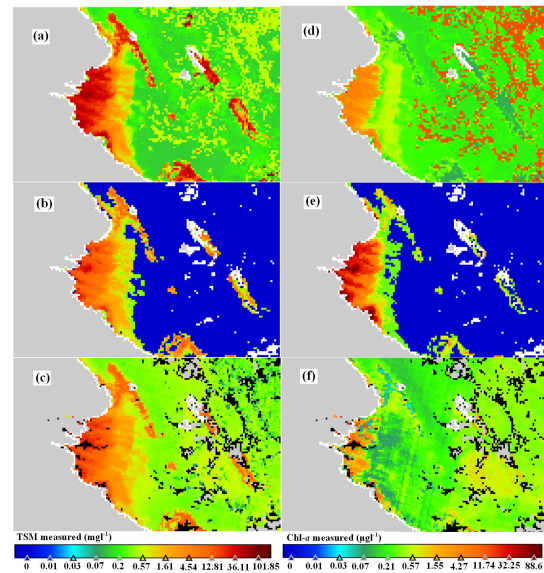


Figure 3. Concentration maps of TSM (a,b,c) and Chl-*a* (d,e,f) derived from MERIS RR image of 31 August 2007. The processing from L1 to L2 was carried out with C2R (a,d), FUB (b,e) and standard ESA processors (c,f).

Figure 4b and Figure 4d present the transect analysis of the TSM and Chl-*a* concentration collected from the *in situ* stations that were located between 28 km and 40 km from the river mouth. The correlation analysis for those 9 stations is presented in Table 1.

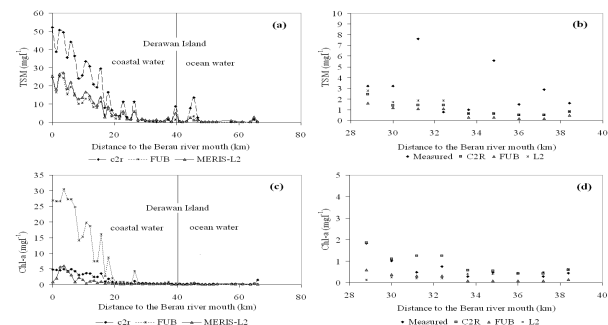


Figure 4. Concentration transects of TSM (a,b) and Chl-*a* (c,d) derived from MERIS RR image and *in situ* measurements (b,d, only) taken at 31 August 2007.

Table 1 shows that in term of the RMSE and  $R^2$ , the TSM of MERIS L2 was closest to the *in situ* data, but no relation could be established. The RMSE of Chl-*a* concentration derived with MERIS L2 was the highest.

Table 1. Summary of the correlation between TSM concentration and Chl-*a* concentration estimation from MERIS data and field data on 31 August 2007 with 9 number of field observation

TSM concentration ( $\text{mg l}^{-1}$ )			
	RMSE	% Difference	$R^2$
C2R	2.88	-44	0.03
FUB	3.13	-64	0.05
L2	2.76	-36	0.05
Chl- <i>a</i> concentration ( $\mu\text{g l}^{-1}$ )			
	RMSE	% Difference	$R^2$
C2R	0.33	47	0.75
FUB	0.54	-65	0.85
L2	0.63	-17	0.53

### 3.3. Remote sensing reflectance

The magnitude and spectral variation of  $R_{rs}$  depend on the IOPs i.e. absorption and backscattering properties of seawater itself, phytoplankton, CDOM and detritus. There were 9 stations with remote sensing reflectance data measured by the Ocean Optic 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  $R_{rs}$ . Consequently, the inter-comparison between *in situ* reflectance data and  $R_{rs}$  retrieved from MERIS L1 as well as MERIS L2 satellite data showed also different degrees of correlation and RMSE. For this study, the  $R_{rs}$  of *in situ* measurements have been calculated using Eq. (1) and Eq. (2). 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 three  $R_{rs}$  outputs obtained from three different algorithms for the 9 stations (data set of 31 August 2007) are plotted in Figure 5.

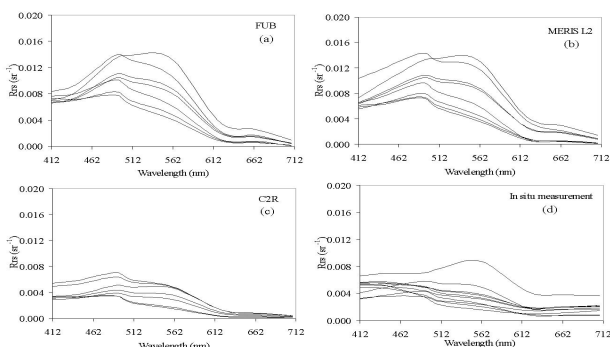


Figure 5. The  $R_{rs}$  derived from MERIS data using different processors (a,b,c) compared to *in situ* data (d) taken at the match-up stations on 31 August 2007.

The  $R_{rs}$  from FUB and MERIS L2 data sets are characterized by a strong slope at short wavelength and have a maximum value at 490 nm (band 3). The  $R_{rs}$  of C2R showed also similar characteristic with the  $R_{rs}$  of FUB and MERIS-L2, where the peak is visible at 490 nm, but with smaller magnitude. In contrast, the  $R_{rs}$  of *in situ* data sets shows different characteristics. The  $R_{rs}$  was relatively high in the blue

wavelength and decreases with increasing wavelength. The RMSE was used to explain the analysis between  $R_{rs}$  measured and  $R_{rs}$  derived from MERIS data, and it is displayed in Figure 6. The  $R_{rs}$  derived from MERIS with FUB and MERIS L2 and  $R_{rs}$  measured were relatively similar at all wavelengths and RMSE decreased at long wavelength. The RMSE between  $R_{rs}$  derived from MERIS with C2R and  $R_{rs}$  measured was higher than ones derived with FUB and MERIS L2 at short wavelength.

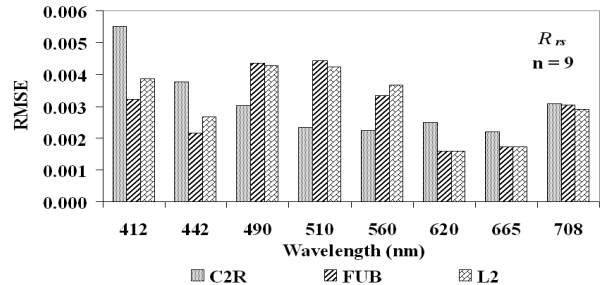


Figure 6. The RMSE between  $R_{rs}$  measured and  $R_{rs}$  derived from MERIS data with C2R algorithm, FUB and MERIS L2

## 4. DISCUSSION

This study demonstrates that the MERIS reduced resolution L1 and L2 data can successfully be used to obtain first estimation of TSM and Chl-*a* concentrations, and also permit to derive remote sensing reflectance in equatorial coastal waters like the Berau estuary in East Kalimantan.

The objective of the study was to estimate and validate TSM and Chl-*a* concentrations from MERIS RR data in tropical coastal waters using different standard algorithm processors. The results indicate that the correlation between TSM retrievals from MERIS satellite and *in situ* measured data were low, indicated by very low  $R^2$  (Table 1). Those can be explained due to the fact that the Berau estuary waters are affected by the Berau river outflows, tidal currents and resuspensions and presence of CDOM absorption. The reference point was located in the river mouth. A number of points at a relatively large offshore distance, however, still indicate high values of TSM, which cause the low correlation between TSM distribution and offshore distance. This may be related with the fact that some points were still relatively close to the coast line or reefs and so, they still were influenced by the coastal and shallow water processes. The *in situ* observations were collected during 18 days, thus the dynamics of the coastal input from the Berau river as well as the ocean and weather were significant.

The TSM derived using the MERIS L2 algorithm gave a slightly better result compared to ones modeled with C2R and FUB. Whereas, C2R and FUB algorithm processors are specially developed for Case-2 waters, while MERIS L2 is a global algorithm, which contain one algorithm for Case-1 and one other for Case-2 waters. Thus, the result of this study indicate that even it was not designed especially for Case-2 waters, MERIS L2 can also be used for deriving TSM in this region.

One of the cause of the insufficient result in retrieving TSM and Chl-*a* concentration in this study maybe due to the atmosphere variability like haze and cloud cover. Such variability and cloud cover hamper the atmospheric corrections on the C2R and FUB algorithms. The bio-optical models included in the Case-2 regional algorithm are a standard case only, based on the special scope of the training data.

This study investigated also the  $R_{rs}$  retrievals at different wavelengths. The results show a large discrepancy between satellite and measured  $R_{rs}$  in the blue wavelength (412 nm), indicated by very low correlation ( $R^2$ ) between MERIS data and *in situ* data. The insufficient or poor atmospheric correction achieved in the blue wavelength domain may be responsible for this. The best accuracy of MERIS data in tropical turbid coastal water of the Berau estuary were reached in bands 3 to 6 with higher discrepancy in the other bands.

The difference between *in situ* measurement and MERIS data can also be due to the pixel heterogeneity. The *in situ* measurements were obtained at point locations that represent a very small homogenous water footprint, while the MERIS sensor records the signal over a larger water surface area, 1.44 km<sup>2</sup>.

The study area is located in an equatorial tropical region, where clouds and atmospheric haze are almost present at all times. Not only because cloud contaminated pixels give an incorrect reflectance, they also can degrade the reflectance accuracy in other parts of the scene. Clouds give an impact to the spatially averaged radiance. The haze in this study has a very high and dynamic variability. This can be proved by the fact that applying MERIS L2, C2R and FUB gave almost similar result on derived  $R_{rs}$ , Chl-*a* concentration and TSM concentration. More details of this research can be found in Ambarwulan et al. (2010).

## 5. CONCLUSIONS

From the results obtained, it can be concluded that the MERIS RR data permit to derive optical water properties like water reflectance  $R_{rs}$  in these equatorial coastal zone with a reasonable accuracy. The standard water quality algorithms (MERIS L2, C2R, FUB) available to derive total suspended matter and Chlorophyll-*a* concentrations from MERIS data however permit only a first approximation of the order of magnitude of constituent concentrations. The MERIS data were analyzed through different Case-2 regional algorithm processors (C2R and FUB) and the global processor (MERIS L2) with different degrees of result. The C2R algorithm showed more robust for estimating Chl-*a* and remote sensing reflectance,  $R_{rs}$ . The relatively poor accuracy is due to the fact that all three ANN algorithms were originally developed and calibrated on coastal waters in temperate regions at higher latitudes, e.g. 30 to 60° north. The highly variable atmospheric conditions, especially at the land - sea boundary in these equatorial regions, seem also to hamper accurate retrievals of water quality constituents. In order to get a better accuracy in estimating water quality concentrations, more appropriate atmospheric correction, taken into account the strong dynamics of the tropical atmospheric conditions, can be recommended.

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