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DISTRIBUTION OF *Chlorophyll-a* AND SEA SURFACE TEMPERATURE (SST) USING MODIS DATA IN EAST KALIMANTAN WATERS, INDONESIA

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Abstract: Regular monitoring of near-shore and open-water parameters for marine management in East Kalimantan waters, Indonesia is still limited. The objective of this research is to determine and interpret the seasonal and spatial variability of sea surface temperature (SST) and Chlorophyll-*a* concentration (Chl-*a*) in East Kalimantan waters. A standard MODIS SST split-window algorithm and empirical Chlorophyll-*a* OC-3M algorithm were used to generate the Level 2 MODIS SST and Chl-*a* images. MODIS or Moderate Resolution Imaging Spectroradiometer is a key instrument aboard the Terra and Aqua satellites. From March 2005 to August 2006, the SST and Chl-*a* were retrieved from the sensor data in East Kalimantan coastal and open-sea waters. *In situ* measurements from near-shore waters were used to validate the MODIS Level 2 data. A comparison of MODIS with *in situ* values for SST and Chl-*a* shows: RMSE=1.21ºC, Bias=-3.42, n=121 and RMSE=1.01mg.m^{-3}, Bias=+2.45, n=75, although some anomalies were observed in the retrievals in both datasets. The analysis of seasonal variations indicates that there was low SST variability between wet and dry season. There was also low variability between SST values in near-shore and open-sea waters. However, for both seasons, open-sea SST was paradoxically found to be warmer than the near-shore waters. The Chl-a maps revealed low Chl-*a* variability between wet and dry season. Different value ranges in Chl-*a* were found between near-shore waters (1.00-56.00 mg.m^{-3}) and open waters (1.00-4.00 mg.m^{-3}). The Chl-*a* values retrieved from MODIS for both seasons were higher in near-shore water. The SST and Chl-*a* in near-shore waters have a low positive interrelationship in wet season. During dry season, the relationship between these two variables varies from positive to negative. This study demonstrated that MODIS Level 2 data from Malaysia Ground Receiving Station (MGRS) can successfully be used to obtain SST and Chl-*a* in Southeast Asian coastal and open waters.

KEYWORDS: Sea Surface Temperature; Chlorophyll-*a*; ocean colour; MODIS; Kalimantan.

Introduction

East Kalimantan waters which consist of Berau Marine Protected Area is well-known as one of the most beautiful areas for coral reef in the world. With 507 species of hard coral, Berau coral biodiversity is considered as the second highest in Indonesia and the third in the world. Among 120 potential outstanding universal values, Derawan islands which are located in Berau waters have been classified as one of the top seven (UNESCO, 2002).

Several studies had shown that the total fish catch from Berau waters has been declining for the past ten years (Ismuranty, 2003) due to the depletion of the coral reefs. Less coral reef areas means less fish stock as coral reef areas are breeding grounds for fish. The cause of coral depletion is well-known, coming primilary from inland activities e.g deforestration and sea temperature changes e.g El-Nino 1997-1998. Continuous monitoring and studies for better marine management however are still very limited (Burke et al., 2002).

In order to maintain the sustainable marine resources in the area, the Indonesian government under Berau Regent Regulation No. 31, 2005 has declared Berau District's coastal and marine area as a marine conservation area (WWF, 2006). Integrated coastal and marine management (ICMM) of this area requires mapping of marine resources and monitoring of basic changes (e.g sea surface temperature, Chlorophyll-*a* concentration) as revealed by Dahuri (2000); Erdmann and Mossa (1990). Previous research has proved that continuous monitoring of SST from space can act as an early warning to detect any SST anomalies that could harm the coral reef such as coral bleaching events (Liu et al., 2003). In day-to-day operations, spatial information on SST and Chl-*a* distribution has been used widely, e.g. in coral-reef management (Udy et al., 2005), fishery forecast (Solanki et al., 2003; Solanki et al., 2005) or as a fundamental data source for coastal management planning (Mumby et al., 1999).

In this study, the capability of geophysical products from Moderate Resolution Imaging Spectroradiometer (MODIS) which is Level 2 sea surface temperature (SST) and Chlorophyll-*a* concentration (Chl-*a*) were assessed in providing ocean parameters for Indonesian waters from May 2005 – August 2006 for a better marine protected areas management.

Materials and Methods

Study area

The study area located within the rectangular region 0º 45' 2.93"N to 4º 39' 43.86"N and 117º 11' 22.38"E to 120º 34' 24.21"E encompasses an area of about 228,254 km^2 (Figure 1).

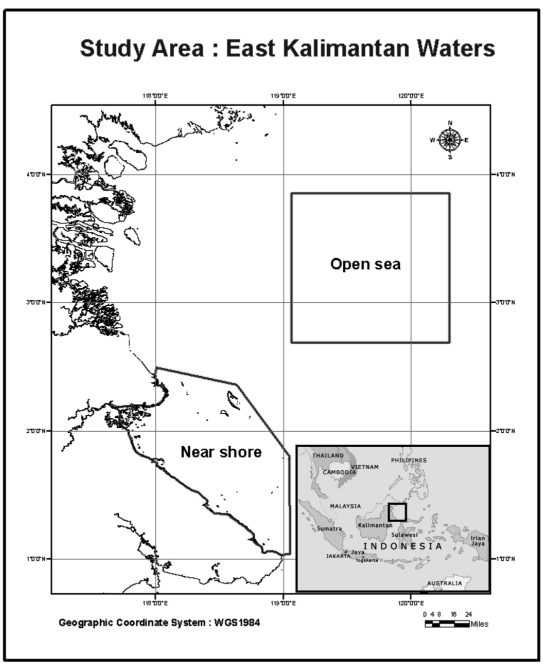


Figure 1: Study area, East Kalimantan waters, Indonesia

In order to achieve the objective of understanding the variability of SST and Chlorophyll-*a* between near-shore and open waters, Kalimantan waters have been subdivided into open-sea area: 17,771 km^2 and near-shore area: 13,046.6 km^2 which is actually the Berau Marine Protected Area. The open sea was defined as the area more than 24 nautical miles (44 km) from the shoreline and near-shore area is the area within 24 nautical miles.

Research Approach

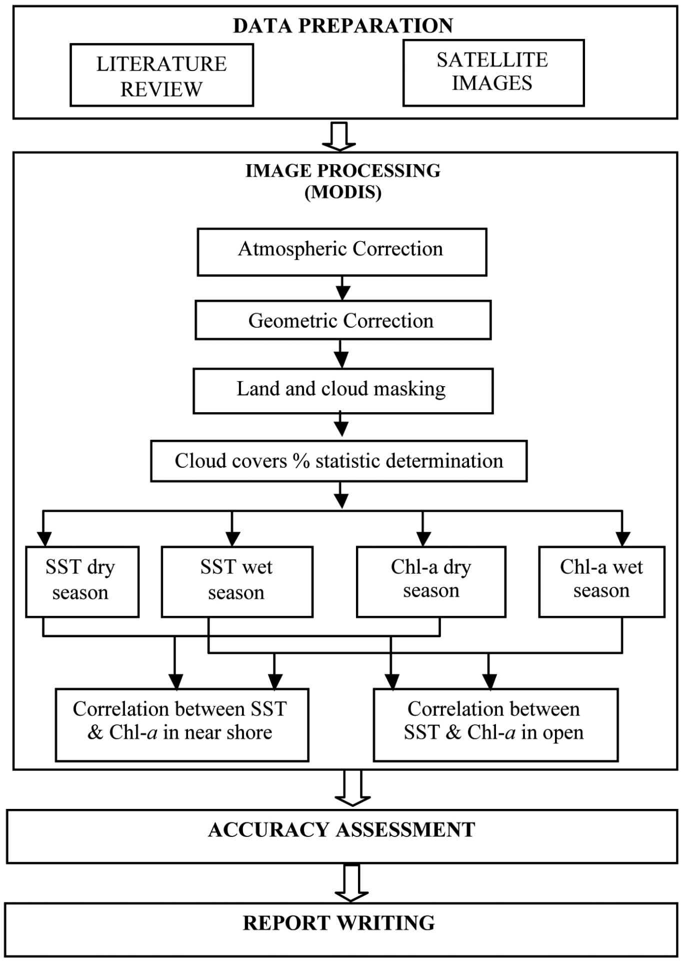


Figure 2: Simplified schema of the research approach

Chlorophyll-a concentration

Chlorophyll-*a* data were processed based on ATBD MOD19, Carder et al. (2003) using empirical chlorophyll-*a* OC3M algorithm as follows:

$$C_a = 10^{0.283 - 2.753R + 1.457 R^2 + 0.659R^4} \quad ;$$

$$\text{where } R = \log10 \left[\frac{R_{rs443} > R_{rs488}}{R_{rs551}} \right]$$

C_a : Chlorophyll-*a* concentration (milligram per cubic metre, $mg.m^{-3}$)
R_{rs} : remote sensing reflectance
R : blue-green band ratio [dimensionless]

Sea Surface Temperature

A total of 21 scenes of SST were processed using split-window technique based on ATBD-MOD25 (Brown and Minnet, 1999). The equation is given as follows:

$$SST = C_1 + C_2 * T_{31} + C_3 * T_{3132} + C_4(\sec(\theta)-1) * T_{3132}$$

where;

T31 is the band 31 brightness temperature (BT)
T3132 is (Band32 - Band31) BT difference
θ is the satellite zenith angle
C_i coefficients listed in Table 1

Table 1 : Coefficients for the MODIS Band 31 and 32 SST retrieval algorithm (Brown and Minnet, 1999)

	Coefficients	
	$T_{30} - T_{31} <= 0.7$	$T_{30} - T_{31} > 0.7$
C_1	1.228552	1.692521
C_2	0.9576555	0.9558419
C_3	0.1182196	0.0873754
C_4	1.774631	1.199584

In situ measurement

In situ measurements were conducted from 11 to 29th August 2006. Measurements of SST were made using the Horiba U-10 water-quality checker. The accuracy of the instrument is ±0.3ºC as stated by Cole-Parmer (2006). SST was measured between 0-20 cm from the ocean surface (bulk temperature). Chlorophyll-*a* concentrations measurement were made using *Aqua*fluor Handheld Fluorometer and Turbidimeter with a detection limit of 0.30 $mg.m^{-3}$ (Turnerdesigns, 2006).

The station locations for the sea truth are shown in Figure 3.

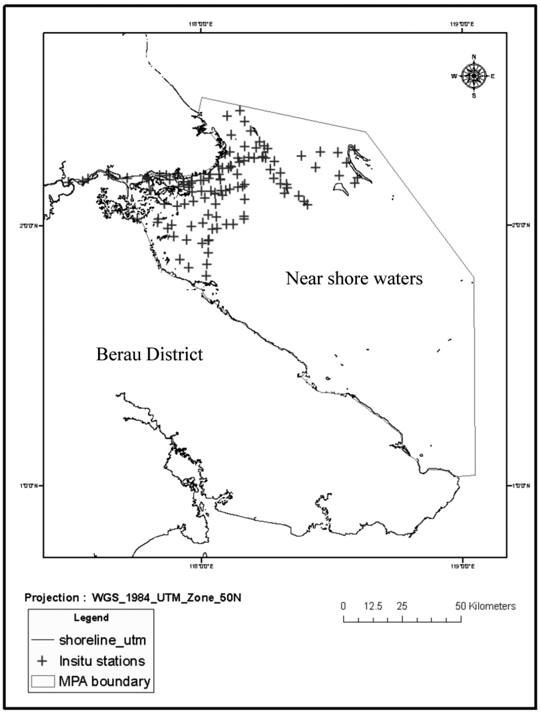


Figure 3: *In situ* sample stations

Results and Discussion

Chlorophyll-a concentrations

In situ Chl-a vs MODIS Level 2 Chl-a

The August 2006 *in situ* Chl-*a* values from 121 stations were compared to the 7th August 2006 MODIS data as shown in Figure 3. We acknowledge there is a time difference between the satellite SST retrieval and the ground measurements, and are fully aware that validation should be carried out at time of satellite overpass, but, as an indication, we performed the comparison and validation exercise.

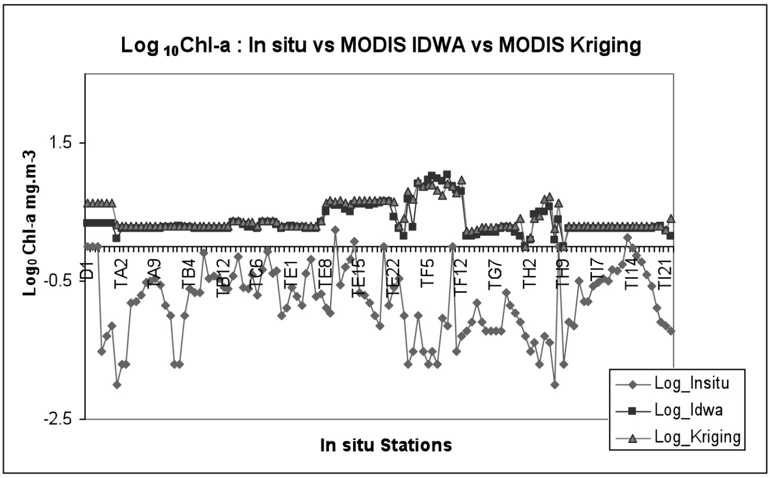
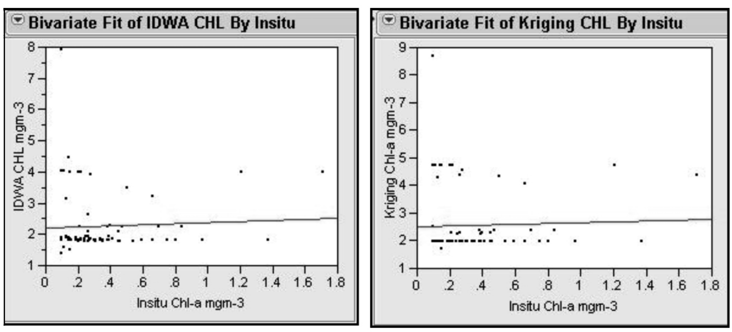


Figure 4 : *In situ* Chl-*a* vs. MODIS IDWA vs. MODIS Kriging

Figure 4 clearly indicated that Level 2 MODIS Chlorophyll-*a* product has overestimated the Chl-*a* values in East Kalimantan waters. The RMSE for *in situ* Chl-*a* vs MODIS IDWA was 1.01 mg.m^{-3} and for *in situ* Chl-*a* vs MODIS Kriging was 1.22 mg.m^{-3}.



IDWA CHL = 2.2111408 + 0.1802974 Insitu (n = 75, r = 0.05)
Kriging CHL = 2.5006469 + 0.1483307 Insitu (n=75, r = 0.04)

Figure 5 : Bivarate Fit of IDWA and Kriging Chl-*a*

The overestimation of low Chl-*a* values by MODIS was also reported by Barbini et al. (2004). Barbini et al. (2004) further described that MODIS sensors tend to underestimate high Chl-*a*. This statement was also supported by Blondeau-Patissier et al. (2004). In his finding, Blondeau-Patissier et al. (2004) stated that, in order to gain more accurate result in detecting Chl-*a* using MODIS, effort should be focussed on improving the atmospheric correction rather than more complicated Chl-*a* algorithms. This might explain very well why there were reasonable differences between MODIS Chl-*a* and *in situ* values in East Kalimantan waters. With none of the validation stations of SeaWiFS Bio Optical Archive and Storage System (SeaBass) located in the study area, this result was expected. However, the RMSE of 1.01 mg.m^{-3} gained can be a good starting point in understanding the variation of actual *in situ* values and MODIS sensors for East Kalimantan waters. A detailed analysis was then carried out in order to understand the variability of Chl-*a* in near-shore and open sea area during the wet and dry season.

Chl-a in the near shore waters

Result shows that there is a large variability of Chl-*a* in the near-shore waters. No unique pattern exists between wet and dry season. The average Chl-*a* in near shore calculated from the imageries were 2.12 mg.m^{-3} during wet season and 3.46 mg.m^{-3} during dry season. The Chl-*a* range for wet season is between 1.00 to 56.00 mg.m^{-3} while it varies from 1.00 to 59.00 mg.m^{-3} during dry season. Our result shows huge differences when compared to previous Chl-*a* mapping in this area. Abu Daya (2004) in his study found that the range of Chl-*a* in near-shore East Kalimantan waters ranges from 0 – 9 mg.m^{-3}. Although it is true to say that it might be due to the different sensors used (SeaWiFS) and different acquisition dates, further research needs to be carried out to compare these two sensors. Blondeau-Patissier et al. (2004) stated that SeaWiFS was more accurate (RMS = 0.24; n = 26) compared to MODIS Level 2 (RMS = 0.40; n = 26). However, as his study was in Northern European waters, the result might be different in tropical waters. One important advantage of MODIS Chl-*a* dataset due to its complex turbid-water algorithm, is the ability to measure Chl-*a* in near-shore waters. Barbini et al. (2004) stated that, SeaWiFS atmospheric correction failed in some near-shore areas. This study proved the capability of MODIS in measuring near-shore Chl-*a*.

Chl-a in the open sea

The value of Chl-*a* ranges from 1.00 to 13 mg.m^{-3} in the East Kalimantan open waters. Further inspection found that the highest concentration value (13.00 mg.m^{-3}), which happened on 10th July 2005, was only from one pixel. Assuming this as noise, the new Chl-*a* range for open waters is 1.00 to 4.00 mg.m^{-3} which is considerably low. The average Chl-*a* calculated from the imageries were 1.00 mg.m^{-3} during wet season and 1.02 mg.m^{-3} during dry season.

Sea Surface Temperature

In situ SST versus MODIS Level 2 SST

The August 2006 *in situ* SST values from 121 stations had been compared to the 7th August 2006 MODIS data as shown in Figure 6 below. As stated earlier, we agree that the time of SST retrieval does not coincide fully with the ground measurements (± 2 week difference). As an indicative exercise, we however conducted a comparison.

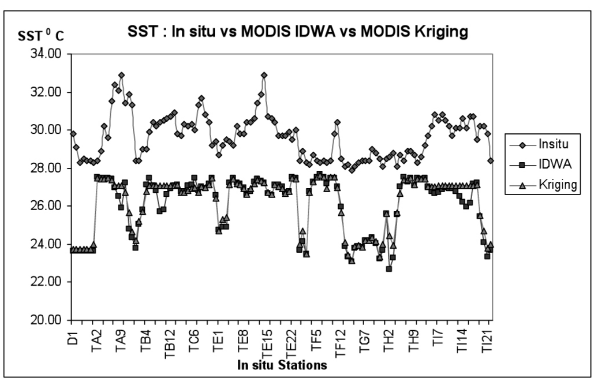
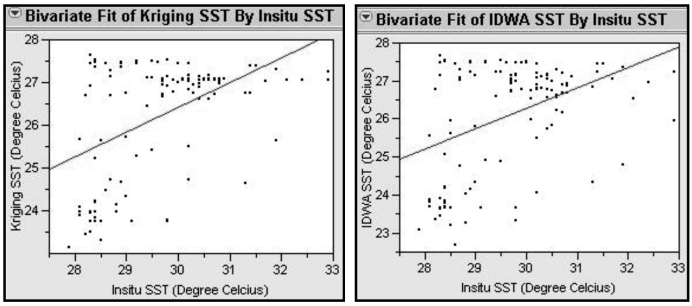


Figure 6 : In situ SST vs MODIS IDWA vs MODIS Kriging

Figure 6 clearly indicated that MODIS data tends to underestimate the SST values in East Kalimantan waters. Further analysis then found that root mean square error (RMSE) for *in situ* SST vs MODIS inverse-distance weighted average (IDWA) was 1.35ºC and for *in situ* SST vs MODIS Kriging was 1.21ºC.



Kriging SST = 8.9002256 + 0.5842152 Insitu SST (n=121, r =0.48)
IDWA SST = 10.163081 + 0.5374372 Insitu SST (n=121, r = 0.42)

Figure 7 : Bivarate Fit of IDWA and Kriging SST

At this stage, one assumption that best explained why MODIS underestimated the SST in this region is because of cold-cloud pixels, which affect neighbouring SST pixels. Further analysis then was conducted on the remaining 20 SST datasets. Three categories of SST values; SST Maximum=Tmax, SST Minimum=Tmin and SST Average=Tavg were discussed. The discussion also focussed on the differences between the SST values for open sea and near shore; during wet and dry season.

SST in the near- shore waters

Result shows that Tmax for the near shore during wet season is 27.66ºC and 27.77ºC during dry season. Throughout the year, Tmax for this region can be concluded as relatively constant. Tmin however shows a fluctuating pattern all year round. The minimum SST value recorded during wet season is 16.49ºC and 8.23ºC during dry season. The low SST values (pixels < 15ºC) could be unrealistic for SST in tropical sea SST such as East Kalimantan waters. Detail inspections to all datasets then revealed that the percentage of the low SST values pixels is very low. It ranged from 0.34% to 5.07% of the total SST pixels in the respective datasets. This confirmed that the low SST values are cold-cloud pixels or edge-cloud pixels and not the true SST.

By setting the cut-off point of valid SST to 15ºC, the average temperature, Tavg was recalculated for all the SST imageries. The new Tavg in near shore for wet season was 26.23ºC and 26.47ºC during dry season.

SST in the open sea

Similar to the near-shore waters, Tmax for open sea during wet and dry season does not vary much. Tmax for the open sea during wet season is 27.66ºC and 27.67ºC during dry season. The average Tmax throughout the year is 27.64ºC. Tmin for open sea is much higher than near-shore waters. Tmin recorded during wet season is 21.93ºC and 14.17ºC during dry season. By setting the cut off point of valid SST to 15ºC, the average temperature was recalculated from the SST imageries and it was found that Tavg for open sea during wet season was 26.69ºC and 26.49ºC for dry season.

Correlation between SST and Chl-a

Having the opportunity to obtain the SST and Chl-*a* at the same time and date is always a dream of marine researchers as it is valuable information for further research application e.g fish forecasting and modelling. Mansor et al. (2001) found that SST and Chl-*a* relationship are the most important variables to model the fish distribution in tropical regions. Solanki et al. (1998), González-Silvera et al., (2004) and Azzaro et al., (2007) revealed that there was negative/inverse correlation between SST and Chl-*a*. Solanki et al. (2003) then used the correlation of SST and Chl-*a* information to model the fish distribution in the Arabian Sea. In contrast to thier finding, this research however found that that there was no specific pattern for correlation between SST and Chl-*a* in East Kalimantan waters except for wet season. Figure 8 shows that the SST and Chl-*a* correlation in wet season has positive relationship. Despite the relatively low Spearman correlation cooefficient (~ Rs = 0.10), the relationship was significant ($p<0.05$). In dry season the relationship varies from negative to positive throughout the dry months.

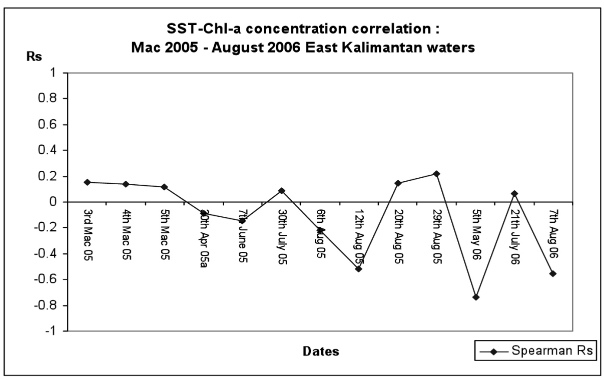


Figure 8: SST and Chl-*a* correlation in East Kalimantan near shore waters

The Spearman non-parametric correlation test has been used due to the non-normal distribution of the data. The analysis reported above was only for the near-shore waters as there was lack of match-up points in open waters. Although MODIS can provide SST and Chl-*a* at the same date and time, these dataset had one drawback: the cloud mask for SST and Chl-*a* is different as shown in Figure 9.

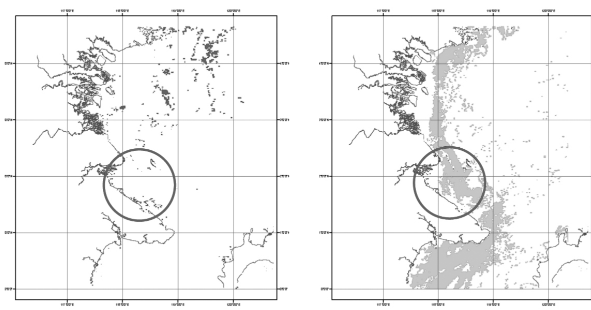


Figure 9 : MODIS cloud mask for SST and Chl-*a* Level 2

Bryan Franz (2006) reported that for MODIS SST Level 2 product, the determination of invalid pixel values is based on how different the pixels value is from the reference SST (Reynolds). If the difference is huge then the pixels will be labelled as SSTWARN. If the SST algorithm could not calculate any values, the pixels will then be labelled as SSTFAIL. As the final SST pixels also took into account the night and day value, sun glint did not effect SST pixels.

The Chl-*a* determination however is very sensitive to sun glint. This is the main reason why both datasets cannot have similar 'cloud mask' and analysis need to be carefully done to select only overlapping pixels for the correlation analysis. The limited overlapping pixels available in open sea of East Kalimantan need to be taken as an important consideration if fish-forecasting model needs to be run using MODIS Level 2 data in this waters.

Conclusion

The seasonal and spatial variability of SST and Chl-*a* in East Kalimantan near-shore and open waters, Indonesia were determined. The minimum, maximum and average values calculated from temporal datasets were examined and reported. *In situ* data were used to validate the accuracy of MODIS Level 2 SST and MODIS Level 2 Chl-*a* data.

The major findings of the research revealed:

SST maps of East Kalimantan waters from March 2005 to August 2006 show that there was low SST variability between wet and dry season. There was also low variability between SST values in near-shore and open-sea waters. However, for both seasons, open-sea SST was found to be paradoxically slightly warmer than the near-shore waters.

Chl-*a* maps of East Kalimantan waters from March 2005 to August 2006 waters revealed that there was low Chl-*a* variability between wet and dry season. There was also low variability between Chl-*a* values in near-shore and open-sea waters. The Chl-*a* values for both seasons is higher in near-shore waters.

SST and Chl-*a* in near-shore waters has low positive relationship in wet season. During dry season, the relationship between these two variables varies from positive to negative.

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