A Study on Chlorophyll Content in Eastern Arabian Coast Using Remote Sensing

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Abstract- *The present work highlights the validation of the chlorophyll product of MODIS and SeaWiFS data with the in situ data as well as the level 2 chlorophyll products of the corresponding sensors. MODIS (L1 and L2) and SeaWiFS (L1 and L2) data are downloaded from the NASA Ocean color web and used for the present study. Other than satellite data in situ chlorophyll samples are also used. The in situ data is collected from the CSIR-NIO, Goa. Relatively cloud free MODIS and SeaWiFS data during the study period of April and May 2010, covering southern part of western Indian continental shelf has been selected for processing. The global processing software SeaDAS has used for processing of the MODIS and SeaWiFS data. Chlorophyll concentration is estimated using the available chlorophyll algorithms in SeaDAS software and compared with the in-situ measured Chlorophyll concentration as well as the Chlorophyll product (L2) distributed by the Ocean Biology Processing Group (OBPG) of NASA for validation. Both SeaWiFS and MODIS Chlorophyll data agreed with in situ measurements. The number of in situ chlorophyll sample points available for comparison with MODIS and SeaWiFS data was only eight. The distribution of the samples was also quite widespread. However, the distribution of in situ chlorophyll was neither systematic nor random. Instead, the data were clustered in Kerala region. The distribution of in situ data has important effects on the estimation of chlorophyll for both SeaWiFS and MODIS data.*

Keywords- Chlorophyll, MODIS, SeaWiFS, In situ

I. INTRODUCTION

The absorption and scattering properties deal with the transmission of light through the water known as inherent optical properties (IOPs). The marine water is optically complex due to biogeochemical oceanic processes like carbon exchanges, phytoplankton dynamics, and responses to climatic disturbances (Franz et al, 2010). The spectral remote sensing reflectance, *Rrs*(λ) is a remotely measurable quantity related to the total absorption and total backscattering coefficients and is highly dependent upon the IOPs. Multiple number of algorithms exists to retrieve the properties as well as the constituents present in the marine water by considering the Rrs(λ) or radiance (RLw). Many algorithms are implemented in the standard NASA ocean color processing code and distributed to the research community through SeaDAS (SeaWiFS Data Analsis System) by the NASA Ocean Biology Processing Group (OBPG). The present study comprises the retrieval of chlorophyll (mg/m^3) concentration and Sea surface temperature (SST) (degree centigrade) from different algorithms using SeaDAS software. The Chlorophyll concentration from MODIS data is estimated using the global ocean colour algorithms namely, OC3, OC2, GIOP and GSM. The OC4, OC3, OC2, GIOP and GSM algorithms are used for the estimation of chlorophyll from the SeaWiFS data. A comparative study has been made between in-situ and satellite derived chlorophyll concentration. Quantitative analysis of SST and chlorophyll helped to understand the distribution of phytoplankton population in the study region. The matchups between in situ and satellite data were sparse because of sensor parameters and also the coverage period of the satellite. The study area has been chosen over a part of the western Indian offshore, i.e, part of Arabian Sea under Latitude 8-23°N and Longitude 72-78°E (Fig. 1). The Arabian Sea is very dip with narrow continental shelf (Prakash et al., 2007). This offshore is highly affected by the winds and currents blowing parallel to the coastline because of the NE and SW monsoon circulation (Shankar, 2001). These winds and currents leads to the upwelling of cold subsurface water. The cold waters are rich in nutrients for the initiation of phytoplankton blooms. It is noticed that Arabian Sea water is more productive than Bay of Bengal Sea water (P. Kumar, 2006). And nearly 70% of the biological sediments are deposited in this region during summer monsoon months (Schwartz, 2006).

The validation of the chlorophyll product of MODIS and SeaWiFS level 1 data with the insiu data as well as the level 2 chlorophyll products of the corresponding sensors is the aim of the present study.

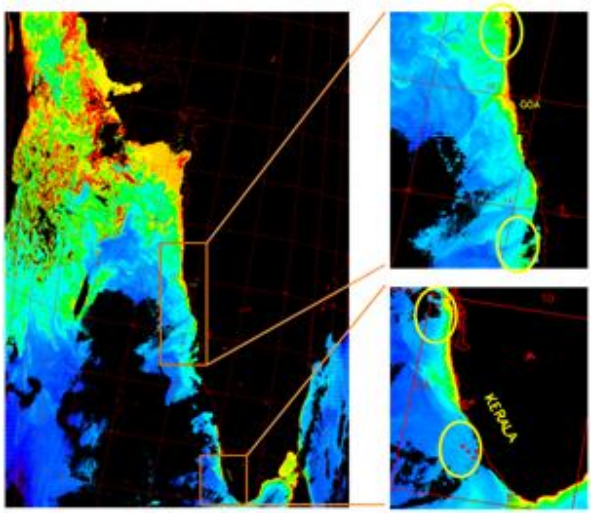


Fig. 1 Sampling location

II. METHODOLOGY

MODIS (L1 and L2) and SeaWiFS (L1 and L2) data are downloaded from the NASA Ocean color web and used for the present study. Other than satellite data in situ chlorophyll samples are also used. The in situ data is collected from the CSIR-NIO, Goa. Relatively cloud free MODIS and SeaWiFS data during the study period of April and May 2010, covering southern part of western Indian continental shelf has been selected for processing. The global processing software SeaDAS has used for processing of the MODIS and SeaWiFS data. Chlorophyll concentration is estimated using the available chlorophyll algorithms in SeaDAS software and compared with the in-situ measured Chlorophyll concentration as well as the Chlorophyll product (L2) distributed by the Ocean Biology Processing Group (OBPG) of NASA for validation.

The global ocean colour algorithms namely Ocean Colour 3 (OC3), Ocean Colour 2 (OC2), Generalized Inherent Optical Properties (GIOP), *Garver-Siegel-Maritorena* (GSM) are used for estimating the chlorophyll concentration from MODIS and SeaWifs data. Other than these algorithms the OC4 algorithm is also used for chlorophyll retrieval from SeaWiFS data. The in situ chlorophyll concentration (mg/m^3) was collected from CSIR-NIO, Goa covering 10 different locations for the different dates of April and May 2010. The data collected on 19th May 2010 and 21st May 2010 is not considered as the corresponding satellite data sets are discarded due to the presence of thick clouds over the study region. The geographical distribution of the sampling locations is shown in Fig. 1 within yellow circles.

III. RESULTS AND DISCUSSION

As an initial analysis of the data distribution and chlorophyll variability, the in situ data collected for all the dates were plotted for the vertical distribution as shown in Fig 2. Chlorophyll concentration vary from minimum value of 0.26 to maximum value of 1.13 mg/m^3 with mean value of 0.55 mg/m^3 at the surface. The minimum, maximum and mean values at the middle depth (15m) are 0.18, 0.82 and 0.52 mg/m^3 and at bottom depth (45m) are 0.02, 0.91 and 0.47 mg m^{-3} respectively. It is observed that the surface chlorophyll concentration is maximum than the middle and the depth chlorophyll. The vertical mixing and upwelling of nutrient rich water may be the reason for the present case of in situ data.

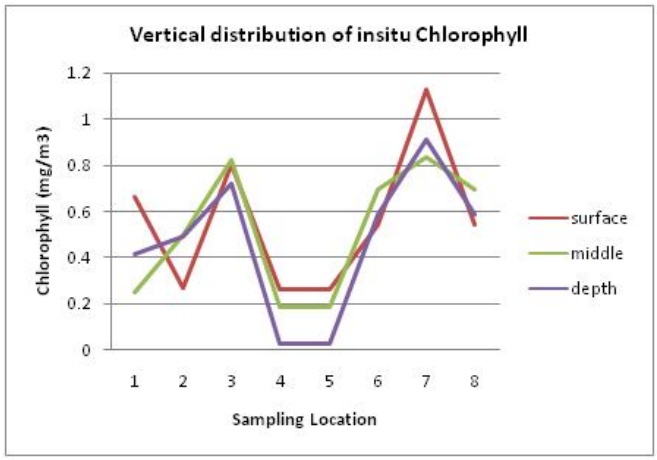


Fig. 2 Comparison of in situ chlorophyll concentration

The chlorophyll images are generated using OC2, OC3, GIOP and GSM algorithms for the study period. The land and cloud portions are masked in black colour for demarcating from cloud and land pixels. The valid ocean pixels are considered for interpreting the data during the study period and the chlorophyll variability of those pixels are represented in colour for better understanding of chlorophyll distribution in the open as well as coastal ocean regions. It is clearly understood that the chlorophyll in the open ocean region is very less and the concentration increases towards the coast. The in-situ measured chlorophyll concentration has been compared with MODIS derived chlorophyll processed using various chlorophyll algorithms. These results of MODIS data were plotted for better understanding of the algorithms performance in the study region, which is shown in Fig. 3.

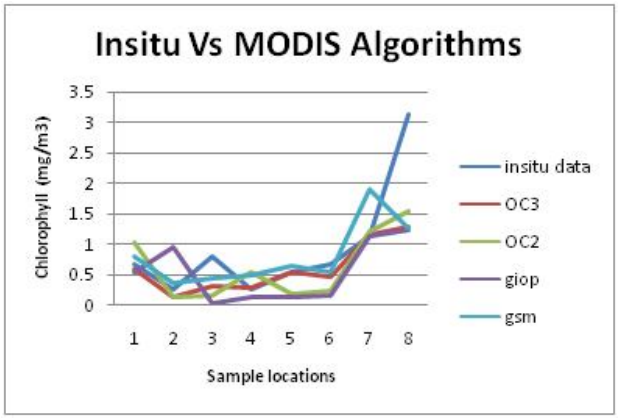
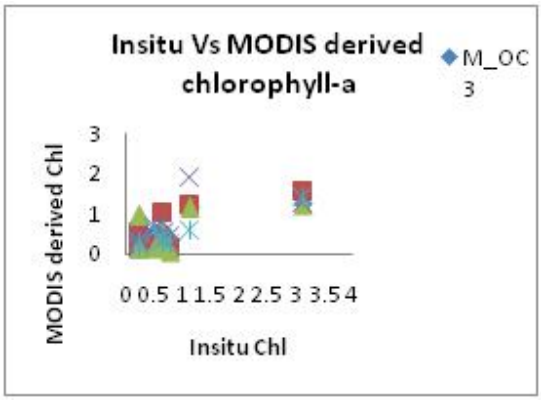


Fig. 3 Comparison of in situ Vs satellite derived (MODIS) chlorophyll concentration using different bio-optical algorithms

From this figure it is clear that the global ocean colour algorithms over estimate or under estimate with respect to the in situ chlorophyll depending on different regions. The coastal system is optically more complex because of short-term coastal upwelling, enhancement of nutrients because of riverine input, anthropogenic activity and biological process (Nagamani et al., 2012). As the entire sample collected belongs to the coastal region, these parameters may be the reason for the bias in the algorithm products. Statistical analyses were performed for the in-situ chlorophyll and the chlorophyll concentration estimated using the global ocean colour algorithms.

Correlation coefficients for MODIS chlorophyll concentration estimated using the global ocean colour algorithms and chlorophyll concentration of Arabian Sea data sets from cruise have resulted the relationship as shown in following figure (fig. 4). Though chlorophyll derived by the OC3 and OC2 algorithms spread out over a large range of values, these algorithm products are well correlated with the in situ data as compared to the GIOP and GSM algorithms, whereas, the OC3 algorithm has shown the highest correlation with the in situ data than other three algorithms. The L2 MODIS product with 0.94 correlation value shows highest correlation than the processed MODIS data.



Parameter	R^2
In situ Vs. OC3	0.69
In situ Vs. OC2	0.57
In situ Vs. GIOP	0.35
In situ Vs. GSM	0.31
In situ Vs. L2 data	0.89

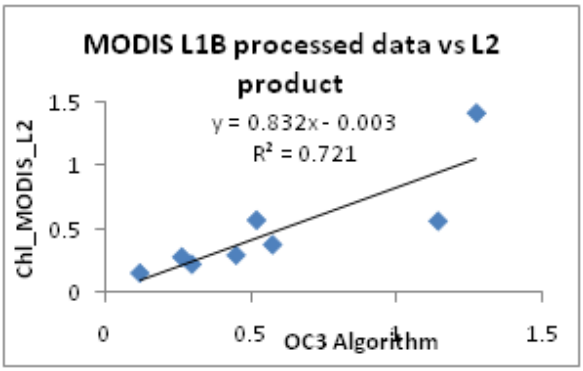
Fig. 4 Comparison of in situ Vs satellite derived (MODIS) chlorophyll concentration using different bio-optical algorithms of the sampling locations during the study period

In situ data Vs MODIS L2 product

The NASA OBPG is providing the chlorophyll product after processing the MODIS raw data. The bio-optical algorithm used by the group is OC3 for the MODIS data. The MODIS level 2 products distributed by NASA OBPG have been correlated with the Arabian Sea data sets from cruise for the validation. The correlation has shown that the level 2 product chlorophyll is very close to the in situ chlorophyll values with the correlation coefficient value of 0.89.

MODIS L1B processed data Vs MODIS L2 product

For the validation of the processed L1B MODIS data with OC3 algorithm as used by the OBPG for the L2 chlorophyll product, the correlation coefficient is calculated between the processed L1B MODIS data and the level 2 chlorophyll product. The R^2 value for this analysis is 0.72, which shows that the processed data value is close to the available chlorophyll product value (Fig. 6).



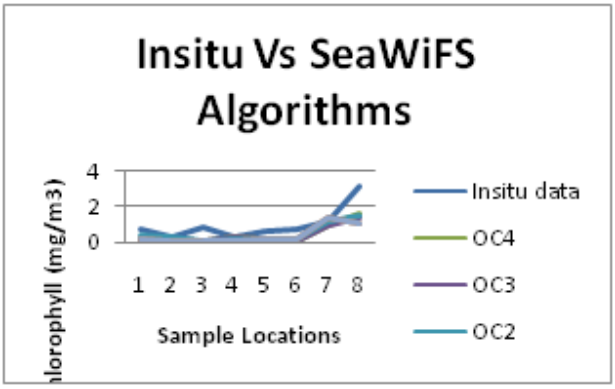
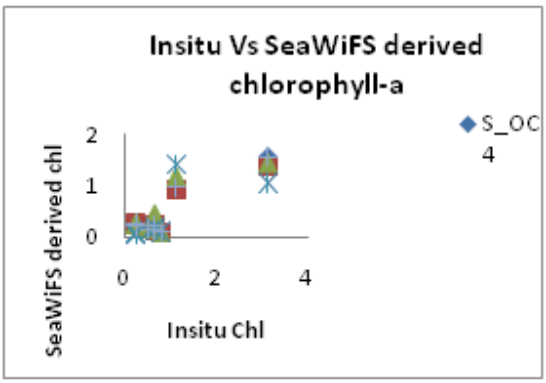


Fig. 6 Comparison of MODIS L1B processed data Vs MODIS L2 chlorophyll product

In situ data Vs SeaWiFS data:



Parameter	R^2
In situ Vs. OC3	0.69
In situ Vs. OC2	0.57
In situ Vs. GIOP	0.35
In situ Vs. GSM	0.31
In situ Vs. L2 data	0.89

Fig. 7 Comparison of In situ data Vs SeaWiFS chlorophyll product

The SeaWiFS L1 data is processed with the OC4 algorithm and correlated with the in situ chlorophyll. It has been found that the chlorophyll from the SeaWiFS data is less correlable with the in situ chlorophyll (R^2=0.296) (Fig: 7).

SeaWiFS L1 processed data Vs SeaWiFS L2 product:

The chlorophyll derived from the level 1 SeaWiFS data is validated with the level 2 chlorophyll product distributed by NASA OBPG. The correlation coefficient, 0.99 (Fig.8) indicates the excellent performance of the SeaWiFS OC4 algorithm with the SeaWiFS L2 product.

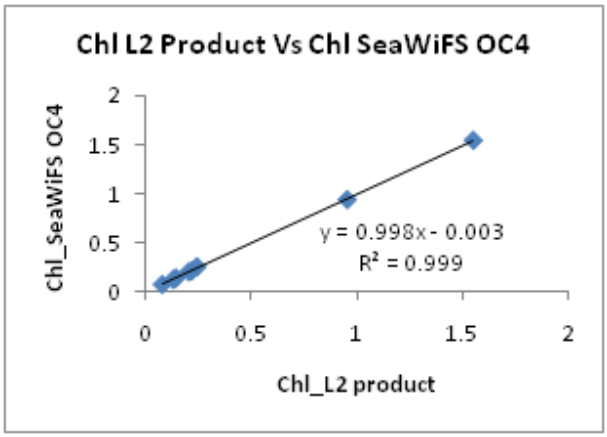


Fig. 8 Comparison of SeaWiFS L1 processed data Vs SeaWiFS L2 chlorophyll product

Table:

	In situ	*S_OC4*	*S_OC3*	*S_OC2*	*S_GIOP*	*S_GSM*	*S_L2 Product*
In situ	1						
S_OC4	0.90	1					
S_OC3	0.88	0.99	1				
S_OC2	0.83	0.97	0.98	1			
S_GIOP	0.68	0.87	0.88	0.93	1		
S_GSM	0.68	0.87	0.88	0.93	0.99	1	
S_L2Product	0.90	0.99	0.99	0.97	0.87	0.87	1

MODIS Chlorophyll Vs SeaWiFS chlorophyll:

The chlorophyll derived from both MODIS and SeaWiFS raw data is plotted to find out the correlation between the datasets (Fig:9). Although the chlorophyll retrieved from SeaWiFS data is less correlated with the in situ data as shown in fig.7, it has shown a good correlation (with correlation coefficient 0.812) with the the MODIS chlorophyll.

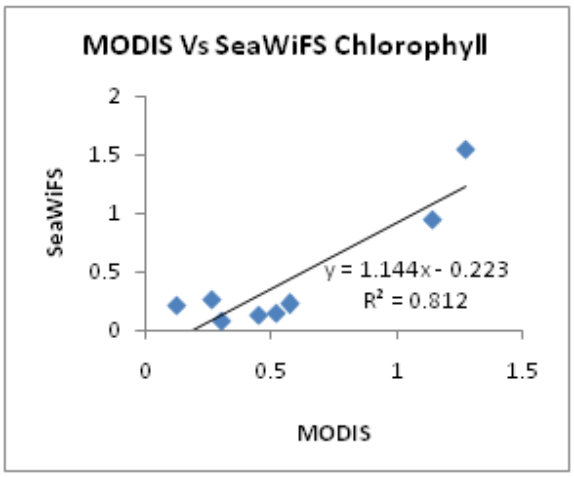


Fig. 9 Comparison of MODIS Chlorophyll Vs SeaWiFS chlorophyll

In situ Chlorophyll Vs MODIS & SeaWiFS Chlorophyll:

As discussed above that the in situ chlorophyll is more correlable with the MODIS data as compared to the SeaWiFS data. The figure (fig.10, 11) shows that the SeaWiFS data underestimated the chlorophyll at station 3, 6 and 8, which may be the reason for the present analysis.

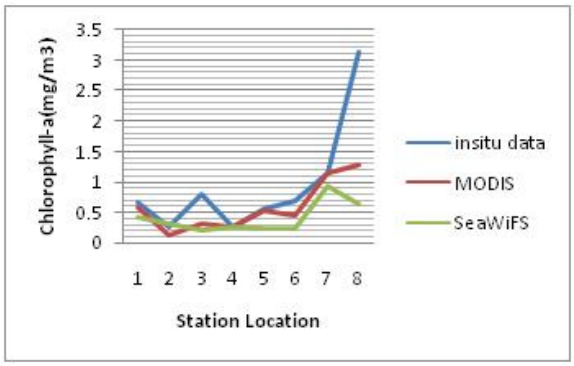


Fig. 10 Comparison of In situ Chlorophyll Vs MODIS & SeaWiFS Chlorophyll

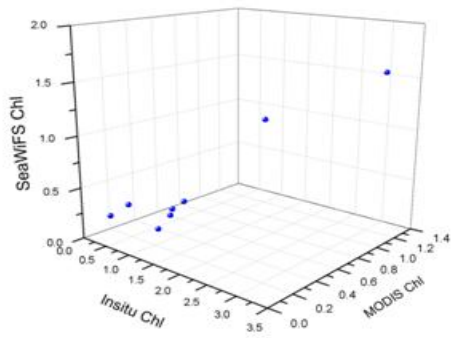


Fig. 11 Comparison of In situ Chlorophyll Vs MODIS & SeaWiFS Chlorophyll

The band used for the algorithm process and the ideal water quality lead for the variation of the chlorophyll than the in situ chlorophyll. The scarcity of in situ data and the collection time may also be the other parameter.

IV. CONCLUSION

Both SeaWiFS and MODIS Chlorophyll data agreed with in situ measurements. The number of in situ chlorophyll sample points available for comparison with MODIS and SeaWiFS data was only eight. The distribution of the samples was also quite widespread. However, the distribution of in situ chlorophyll was neither systematic nor random. Instead, the data were clustered in Kerala region. The distribution of in situ data has important effects on the estimation of chlorophyll for both SeaWiFS and MODIS data.

The surface water contains more chlorophyll as confirmed from the vertical distribution of in situ chloropjhyll-a. The accuracy of the algorithms generally degrades rapidly with increasing optical complexity, especially the GIOP and GSM algorithms. The OC2 algorithm is shown to work relatively better in the Karanataka region (sample no 6 and 7) than other locations, while the GIOP and GSM algorithm have overestimate and underestimate throughout the sampling locations. The OC3 algorithm has shown adequate accuracy with the R^2 value of 0.690 and has been found to be working good for the retrieval of chlorophyll concentration in the Arabian Sea than OC2, GIOP and GSM algorithm. The nutrient input is responsible for the higher chlorophyll concentration in the northern Arabian Sea. The SeaWiFS chlorophyll is less correlable for the present region. The analysis with more number of in situ data may lead for better result of both Satellite data. The comparison between in-situ and all the existing chlorophyll algorithms shows the efficiency of these algorithms for quantification of chlorophyll in coastal waters and hence the need to develop regional algorithms for better quantification.

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