View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NOPR

Indian Journal of Geo Marine Sciences
Vol. 48 (09), September 2019, pp. 1370-1376

Validation of chlorophyll-a and sea surface temperature concentration and their relationship with the parameters—diffuse attenuation coefficient and photosynthetically active radiation using MODIS data: A case study of Gujarat coastal region

Vinod K. Yadav[1,2*], Shrinivas Jahageerdar[2], & J. Adinarayana[1]
[1]Centre of Studies in Resource Engineering (CSRE), Indian Institute of Technology, Powai, Mumbai. India
[2]Central Institute of Fisheries Education (CIFE), Versova, Andheri (W), Mumbai, India
*[E-mail: vinodkumar@cife.edu.in]

Received 14 March 2018; revised 24 July 2018

In-situ data of chlorophyll-*a* concentrations (Chl-a) and sea surface temperature (SST) of the Gujarat region for the period, 2002-2009 were obtained from Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. Out of nearly 100 sampling points, 22 and 67 points qualified for comparison with the satellite measurements of Chl-a and SST, respectively. Chl-a concentrations were estimated from the MODIS satellite data (4 km resolution) with the existing global ocean color algorithms, namely, OC2V4, OC4V4, and OC3M. The SST was calculated with the help of bands 31 and 32 using MODIS-Aqua sensor long wave SST algorithm and European Centre for Medium-Range Weather Forecasts (ECMWF) assimilation SST retrieval model (split window method). The satellite images were processed using global Sea WiFS Data Analysis System (SeaDAS) software v.7.3.1. Chl-a retrieved from OC3M algorithm had high coefficient of determination (R^2=0.74) and less root mean square error (RMSE=1.24) as compared to OC2V4 and OC4V4 (R^2=0.541 & 0.542 and RMSE=1.94 and 1.84, respectively) with *in-situ* data. The SST retrieved from MODIS-Aqua sensor long wave SST algorithm had a high coefficient of correlation as compared to ECMWF assimilation model (0.798 & 0.32 respectively) with *in-situ* data and RMSE were 0.80 and 2.65, respectively. SST and Chl-a showed an inverse correlation, with a coefficient of correlation (R) =0.530. Daily retrieval of Chl-a and SST value had very high degree of correlation with remote sensed eight days composite and monthly composite value (0.958 & 0.876, respectively). Retrieval of the value of diffuse attenuation coefficient at 490 nm wavelength (Kd or Kd_490), photosynthetically active radiation (PAR) and vertical attenuation coefficient of PAR (Kd(PAR)) were done and found that Kd and Kd(PAR) had very high degree of positive correlation (R=0.994). In addition, it was found that PAR had a positive correlation with SST(R=0.512) and negative correlation with Chl-a (R=-0.446). The range of this parameter values supports the case-I water and fish assemblage area.

[**Keywords**: MODIS; Chlorophyll-a; Sea surface temperature; Validation; *In-situ;* Algorithms]

Introduction

Remote sensing is one of the most efficient and modern tools for understanding the dynamics of our planet[1]. Sea-viewing wide field-of-view sensor (SeaWiFS) that was launched on the OrbView-2 spacecraft in August 1997 and the moderate resolution imaging spectroradiometer (MODIS) that were launched on the NASA Earth Observing System (EOS) satellites Terra and Aqua, in December 1999 and May 2002, respectively. With these missions, we entered a new era of ocean colour remote sensing that is expected to provide a highly consistent time series of near-synoptic and global data for many years to come. The advent of satellite technology, which provides repetitive and wide area coverage, has revolutionized the oceanographic observations in the past decades and made easy-to-map ocean geophysical parameters and their inter-linkages. The satellite ocean colour measurements data are important for understanding the atmospheric and ocean color parameters. In this paper, remote sensing of water quality parameter was involved in estimation of chlorophyll-a (Chl-a), Sea Surface Temperature (SST), diffuse attenuation coefficient at 490 nm wavelength (Kd or Kd_490) and photo-synthetically active radiation (PAR).

Chl-a is the primary phytoplankton pigment for photosynthesis of marine algae in the ocean. The concentration of Chl-a is often considered as an index of biological productivity and, in an oceanic environment, it can be related to fish production. Marine researchers found that the measurement of

SST is essential to understand how our ocean behaves: understand its relationship with ocean flora and fauna and not least to understand the global climate. Operationally, SST information has been used as input for atmospheric circulation/forecast models[2]. In addition, SST is an important factor, which leads the fish activity levels to increase, or decrease, makes fish move into certain areas, and influences feeding and reproductive activity. The quantity of light available for photosynthesis is termed as PAR which is measured as the amount of energy flux in the wavelength range of 400 to 700 nanometer from the sunlight. The growth of phytoplankton is controlled by PAR, and hence it is used in regulating the composition and evolution of marine ecosystem. Kd (or Kd_490) may be used to describe the optical properties of ocean water. It increases with biomass and decreases with non-algal turbidity[3]. Thus, Kd gives a clear idea of transparency of the water column.

In the present study, Chl-a concentrations estimated from the MODIS satellite data (4 km resolution) with the existing global ocean colour algorithms, namely, OC2V4, OC4V4, and OC3M and SST was calculated with the help of bands 31 and 32 using MODIS-Aqua sensor long wave SST algorithm and European Centre for Medium-Range Weather Forecasts (ECMWF) assimilation SST retrieval model (split window method). The derived Chl-a concentration and SST from remotely sensed imageries were compared with *in-situ* data of Chl-*a* concentrations and SST of the Gujarat region for the period, 2002-2009 obtained from INCOIS, Hyderabad. In addition, the retrieved value of Kd and PAR from MODIS remote sensed imageries were compared with the satellite retrieved value of SST and Chl-a.

Data and Methods

In-situ data of Chl-a and SST of the Gujarat region for the period, 2002-2009 were obtained from INCOIS, Hyderabad. Out of nearly 100 sampling points, 22 and 67 points qualified for comparison with the satellite measurements of Chl-a and SST, respectively. Miroslaw et. al, 2003[4] had also pointed that out of the total of 56 ship days at sea between September 2000 and October 2001, only 14 days qualified for the comparison with the satellite measurements of Chl-a. Chunhuaqiu et al., (2009)[5] had discussed that the annual average availabilities of SST from MODIS sensor were 68.42%. The processing of data from MODIS onboard Aqua satellite (hereafter referred as MODISA) was done by using SeaWiFS data analysis system (SeaDAS) software. The typical satellite data processing flowchart is shown in Figure 1. Processing can go from level-1A data to level 3 taking the geo processing file. The detailed description of processing can be seen on the web address - https://seadas.gsfc.nasa.gov[6].

Chl-a Algorithm

The OC2V4, OC4V4 and OC3M algorithm has the following functional form as shown

(i) Chl_OC2V4=10.0^(a[0]+a[1]*R+a[2]*R^2+a[3]*R^3+a[4])

Where R=Reflectance at 490nm/ Reflectance at 555nm and a= (0.2974,-2.2429,0.8358,-0.0077,-0.0929)

(ii) Chl_OC4V4=10.0^(a[0]+a[1]*R+a[2]*R^2+a[3]*R^3+a[4]*R^4)

Where R=$\log_{10}$ (R_{rs}443>R_{rs}490>R_{rs}510/R_{rs} 555) (maximum band ratio) and a=[0.366,-3.067,1.930, 0.649,-1.532]

(iii) OC3M algorithm

Log[Chl]= a[0]+a[1]X+a[2]X^2+a[3]X^3+a[4]X^4

Where X=log [max (R_{rs}(443),R_{rs}(489))/R_{rs}(555)] and the coefficients a0, a1, a2, a3, a4 are 0.283, -2.753, 1.457, 0.659, and -1.403, respectively

Estimation of SST

For the calculation of SST, first, the brightness temperature was calculated from the spectral emissive radiance data using the following standard formula for Newton-Boltzmann as given in Eq. 1:

$$L = 2*h*c^2*\lambda - 5 / \left[e^{(h*c/k*\lambda*T)} - 1 \right] \quad \text{... (1)}$$

where

L is the radiance (watts/m^2/ steradian/m), h is the Planck's constant (joule-second)

c is the speed of light in the vacuum (m/s), k is the Boltzmann gas constant (joules/Kelvin)

λ is the band or detector center wavelength (m), T is the temperature (Kelvin)

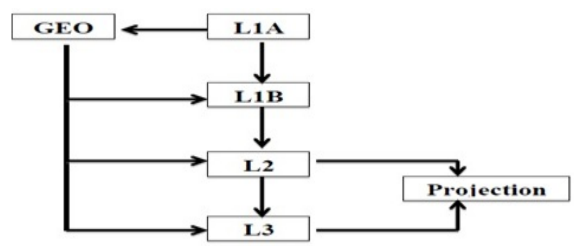

Fig. 1 — Typical satellite data processing flowchart in SeaDAS

Sea surface temperature was calculated from this brightness temperature data. This temperature is the sea surface skin temperature ranging from 5- to 10-µm depth[7]. The algorithms implemented for SST calculation are MODIS-Aqua –sensor long wave SST algorithm and MODIS-SST European Centre for Medium-Range Weather Forecasts (ECMWF) based model.

MODIS-Aqua –sensor long wave SST algorithm

For, dBT<= 0.5:

sst=a00+ a01*BT1+a02 * dBT*bsst+a03*dBT*(1.0/mu-1.0)

For, dBT>= 0.9:

sst= a10 +a11*BT11+a12*dBT*bsst+a13*dBT*(1.0/mu-1.0)

For, 0.5 <dBt< 0.9:

sstlo=a00+a01*BT11+a02*dBT*bsst+a03*dBT*(1.0/mu-1.0)

ssthi=a10+a11*BT11+a12*dBT*bsst+a13*dBT*(1.0/mu-1.0)

sst = sstlo + (dBT-0.5)/(0.9-0.5)*(ssthi-sstlo)

dBT = BT11 - BT12

Where;

BT11 = brightness temperature at 11 um, in deg-C

BT12 = brightness temperature at 12 um, in deg-C

bsst = baseline SST, which is either sst4 (if valid) or sstref (from oisst) mu = cosine of sensor zenith angle

Coefficients for the MODIS-Aqua –sensor long wave SST algorithm are mentioned in Table 1.

ECMWF assimilation SST retrieval model

$$\text{modis\_sst} = c_1+c_2*T_{31}+c_3*T_{3132}+c_1*(\sec(\theta)-1)*T_{3132} \quad \text{... (2)}$$

T_{31} is band 31 brightness temperature (BT),

T_{3132} is (Band32 - Band31) BT difference

θ is the satellite zenith angle

This algorithm differentiates atmospheric vapour load using the difference between the brightness temperatures (T3132) for the 11- and 12-µm bands (MODIS band numbers 31 and 32). Coefficients are determined for T3132 greater or less than 0.7 K. While implementing, the coefficients are weighted by the measured T3132.

Coefficients for the MODIS_SST retrieval algorithm derived using ECMWF assimilation model is mentioned in Table 2

Table 1 — Coefficients for the MODIS-Aqua –sensor long wave SST algorithm[8]

Coefficient	Respective coefficients value
a00,a01,a02,a03	1.1520, 0.9600, 0.1510, 2.0210
a10,a11,a12,a13	2.1330, 0.9260, 0.1250, 1.1980

Diffuse attenuation coefficient (Kd)

The Kd of oceanic water is a property that can be inferred from the ocean-color satellite data. Light availability is a critical regulator of oceanic and coastal production of phytoplankton. The measurement of vertical Kd is of particular interest for this purpose, which defines the presence of light versus depth. The knowledge of the optical attenuation within the upper ocean water column is also useful to understand the warming of the upper ocean, which occurs through the absorption of solar irradiance (400- 800nm).

Kd_490, the diffuse attenuation coefficient of down welling irradiance at 490 nm in m^{-1} were obtained by using equation (3) and (4).

$$\log_{10}[K_{bio}(490)] = a_0 + \sum_{i=1}^{4} a_i \log_{10}[R_{rs}(\lambda_{blue}) / R_{rs}(\lambda_{green})] \quad \text{... (3)}$$

(https://oceancolor.gsfc.nasa.gov/atbd/kd_490/)[10]

$$\text{Kd\_490} = K_{bio}(490) + 0.0166 \quad \text{... (4)}$$

(https://oceancolor.gsfc.nasa.gov/atbd/kd_490/)[10]

The coefficient of a0, a1, a2, a3 and a4 for MODIS sensor are -0.8813,-2.0584, 2.5878,-3.4885, and -1.5061. The coefficients were derived using version2 of NASA bio-Optical Marine Algorithm dataset (NOMAD)

Photosynthetically active radiation (PAR)

For ocean color applications, PAR is a universal input used in modelling marine primary productivity. Implementation of this algorithm is contingent on the availability of observed top-of-atmosphere radiances in the visible spectral regime that does not saturate over clouds. The algorithm applies to MODIS, MERIS, SeaWiFS, and VIIRS, but it can be operated

Table 2 — Coefficients for the MODIS_SST retrieval algorithm retrieved using ECMWF assimilation model[9]

	Coeffients	
	$T_{30} - T_{31} <= 0.7$	$T_{30} - T_{31} > 0.7$
C_1	1.11071	1.196099
C_2	0.9586865	0.9888366
C_3	0.1741229	0.1300626
C_4	1.876752	1.627125

on all ocean color sensors (https://oceancolor.gsfc.nasa.gov/atbd/par)[11]. A detailed description of the algorithm can be seen in technical report volume 22, Frouin and Werdell, (2002)[12]. PAR is the measure of the light attenuation of the water column. Vertical attenuation coefficient of PAR (Kd (PAR)) determine the light available for aquatic photosynthetic, were obtained by using equation (5).

$$Kd\ (PAR) = 0.6677 * Kd\ (490)^{0.6767} \quad \ldots (5)$$

Results and Discussion

SST and Chl-a

The daily images of SST and Chl-a were processed in SeaDAS (version 7.3.1) software taking L1A MODIS image. For the calculation of Chl-a, reflectance value at different wavelength was recorded, and suitable algorithms were used. For the calculation of SST, first, the brightness temperature was calculated from the spectral emissive radiance, and then suitable algorithms were used. The values of Chl-a and SST can be retrieved by developing a regional bio-optical algorithm or by the existing algorithms developed for a given area. To develop a regional algorithm, a large number of in-situ measurements are required. However, in the present study, the numbers of data points available were not sufficient to develop a regional algorithm. Hence the Chl-a and SST for the present study were extracted using the existing bio-optical algorithms of Chl-a and sea surface temperature from MODIS image. The results of the different algorithms for Chl-a and SST retrieval were tested with the in-situ data set obtained for the Gujarat region during the period January 2002 to December 2009. It was found that Chl-a retrieved from OC3M algorithm was more reliable as it had a high coefficient of determination (R^2=74%) and less root mean square error (RMSE=1.24) as compared to OC2V4 & OC4V4 (R^2=54.1 & 54.2% and RMSE =1.94 & 1.84 respectively) with *in-situ* data (Fig. 2). The SST retrieved from MODIS- Aqua sensor long wave SST algorithm had a high coefficient of determination compared to ECMWF assimilation model (0.798 & 0.32 respectively) with *in-situ* data and RMSE were 0.80 and 2.65 respectively (Fig. 3). Hence, it can be concluded that OC3M and MODIS- Aqua sensor long wave SST algorithm are the best algorithms for retrieving their remotely sensed value. Chl-a and SST are measured in mg/m^3 and °C respectively

The daily retrieval of Chl-a and eight days composite (average) value of Chl-a (retrieved by OC3M algorithm) had a high degree and significant correlation (R=0.96, Table 3). In addition, the daily retrieval of SST and monthly composite (average) value of SST (retrieved by MODIS Aqua sensor long wave algorithm) had a very high degree and significant correlation (R=0.88, Table 4). These results indicate that in the absence of availability of daily Chl-a and SST values due to reasons like the foggy or unclear atmosphere, etc., eight days average value of Chl-a and monthly average value of SST can be used for further study.

Chl-a and SST retrieved by MODIS Aqua sensor long wave and OC3M algorithm respectively were negatively correlated, with the coefficient of correlation R = -0.53 & R^2 =28.1% (Fig. 4). The

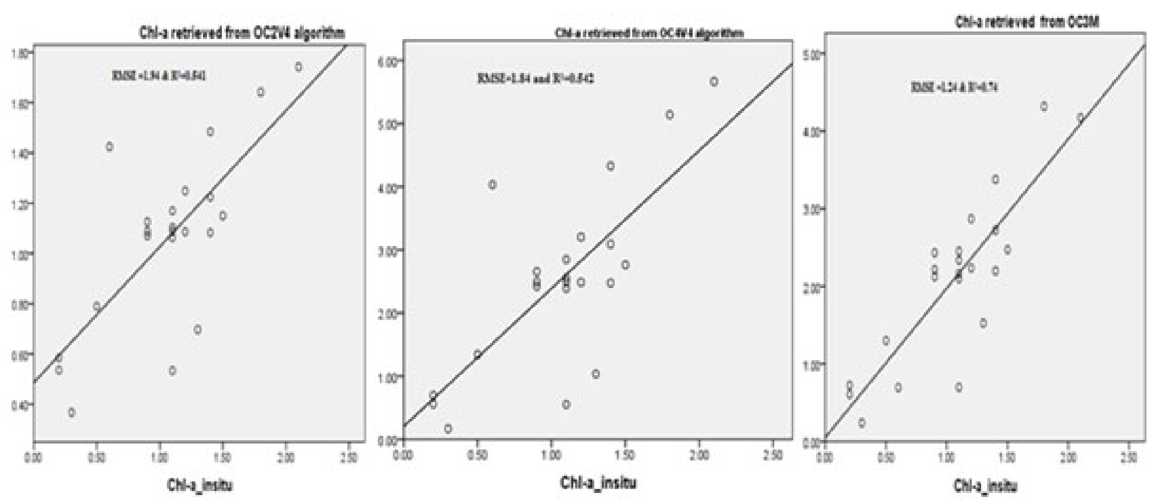

Fig. 2 — Relation between in-situ Chl-a and Chl-a retrieved by OC2V4, OC4V4, and OC3M algorithm (unit of Chl-a is mg/m^3)

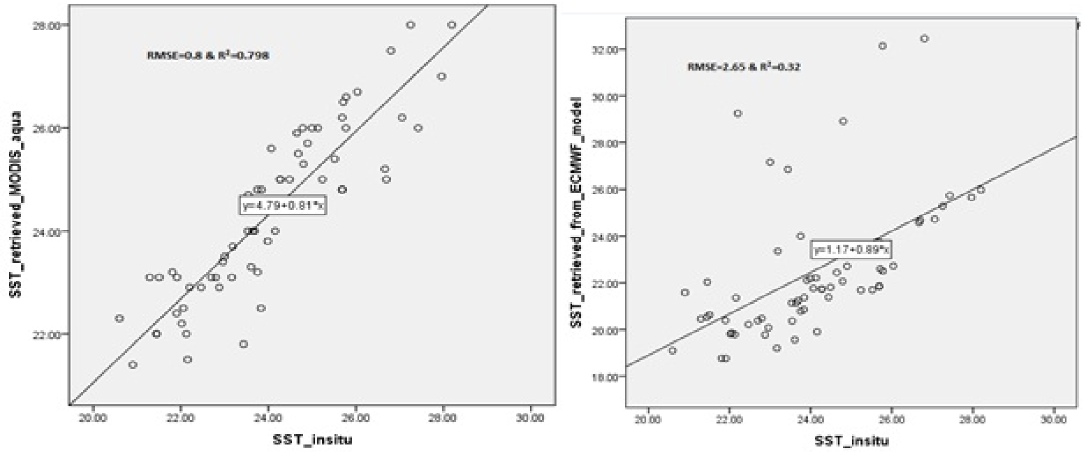

Fig. 3 — The relation between *in-situ* SST and SST retrieved by MODIS Aqua sensor long wave and ECMWF algorithm (unit of SST is °C).

Table 3 — Correlation between daily Chl-a and eight days composite (average) Chl-a value (Sample size=27)

	Composite Chl-a	Daily Chl-a
Composite Chl-a	1	
Daily Chl-a	0.958**	1

**. Correlation is significant at the 0.01 level.

Table 4 — Correlation between Daily SST and Monthly composite SST Value (Sample size=67)

	Composite SST	Daily SST
Composite SST	1	
Daily SST	0.876**	1

**. Correlation is significant at the 0.01 level.

inverse correlation may be attributed mainly to the upwelling process. When upwelling occurs, the bottom layer with colder water and rich nutrient will rise to the surface and will encourage phytoplankton blooms. The coefficient of determination (R^2 = 28.1%), means that SST had 28.1% of contribution to the variation in Chl-a concentration, while the remaining of 71.9% is influenced by other factors together. The other factors probably are current, wind, salinity, run-off, rainfall, etc. (Nurdin et al., 2013)[13].

According to Nurdin et.al (2013)[13] also, SST and Chl-a showed an inverse correlation, with coefficient of correlation at R=0.542 and R^2=0.294.

Relationship of PAR with SST & Chl-a

The range of the PAR during the study period varies from 36.50 to 52.19 Einstein/m^2/day with the average value 42.36 Einstein/m^2/day. It was observed that the Photo Synthetically Active Radiation (PAR) distribution in the study area is showing high when SST is high, and Chl-a is low. Hence, PAR is experiencing an inverse relationship with Chl-a and a linear relationship with SST (Fig. 5). A similar

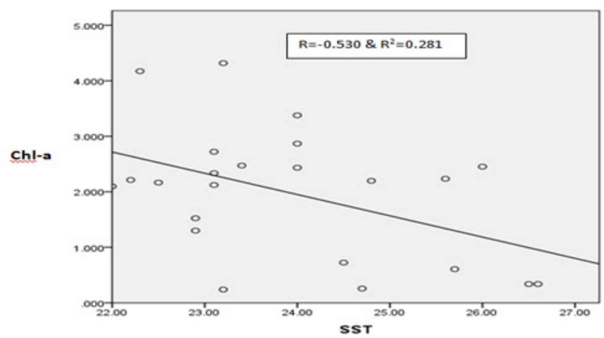

Fig. 4 — Relation between Chl-a (mg/m^3) and SST (°C) retrieved from OC3M algorithm and MODIS Aqua sensor long wave and ECMWF algorithm

observation had been found by Madhavan et al. (2015)[14] along the Nagapattinam coast of Tamilnadu.

Relationship of Kd (PAR) & Kd (490)(or Kd) with Chl-a

Kd (PAR) and Kd (490) retrieved by MODIS Aqua sensor had very high correlation with Chl-a, with coefficient of determination R^2 =0.732 and 0.712, respectively (Fig. 6). In addition, Kd (490) and Kd (PAR) had very high degree of positive correlation (R=0.994) (Fig. 6). Morel et. al., (2007)[15] observed R^2 between Kd (490) and Chl-a was 0.983.

Summary and Conclusion

Remote sensing of Indian Ocean chlorophyll concentrations is the most efficient way to detect large-scale changes in phytoplankton biomass driven by seasonality and climate change. The three different algorithms OC2V4, OC4V4 and OC3M were used to validate the *in-situ* data of Gujarat region (The year 2002 to 2009) and OC3M was found the best one (R^2=0.74 & RMSE=1.24). MODIS-Aqua sensor long wave SST algorithm and ECMWF assimilation, SST

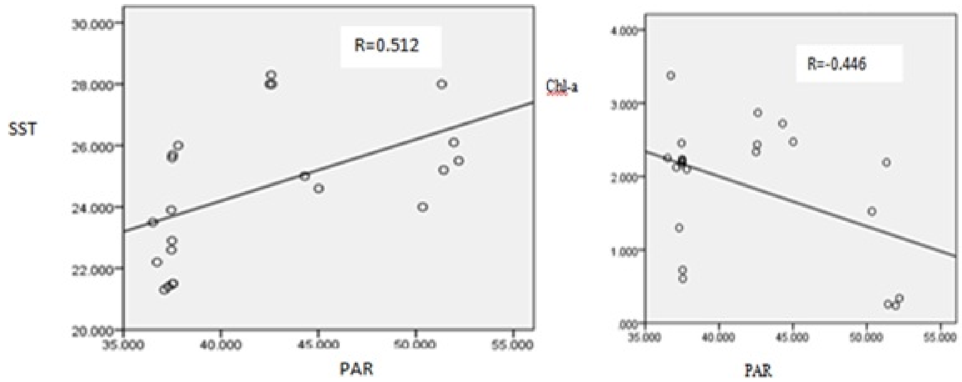

Fig. 5 — Relationship of PAR with SST and Chl-a

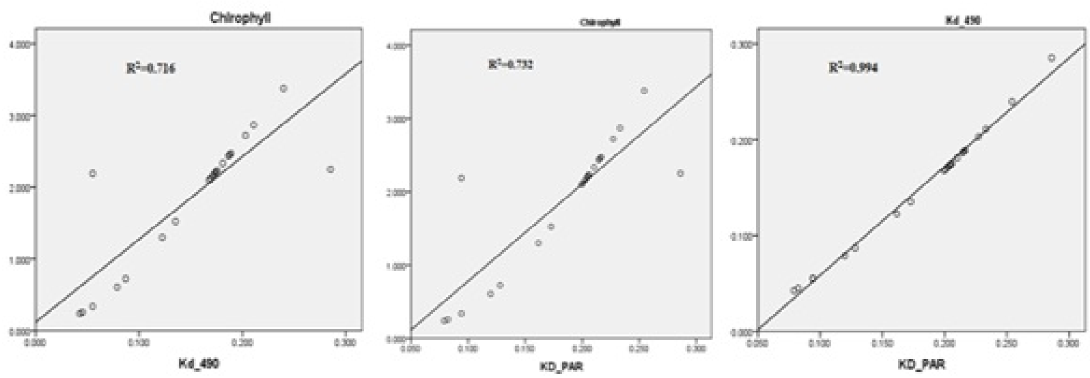

Fig. 6 — Relationship between Kd (490), Kd (PAR) and Chl-a

retrieval model, were used to retrieve the SST value from remotely sensed imageries. The said two models were used to validate the *in-situ* data of SST of the above-said area for the said duration and found that first one was the best (R^2=0.798 and RMSE=0.80). Daily retrieval of Chl-a and SST value had very high degree of correlation with eight-day composite and monthly composite value (0.958 & 0.876, respectively). Hence in the absence of daily Chl-a and SST value due to the foggy or unclear atmosphere, eight days and monthly average value respectively can be taken for the further study. The retrieval of value of Kd (490), PAR and Kd (PAR) was done and found that Kd (490) & Kd (PAR) have very high degree of positive correlation (R=0.994). Kd (PAR) and Kd (490) retrieved by MODIS Aqua sensor had very high correlation with Chl-a, with coefficient of determination R^2 =0.732 and 0.712, respectively. In addition, it is found that PAR had a positive correlation with SST (R=0.512) and negative correlation with Chl-a (R=-0.446). The range of the all the 4 variables (SST, Chl-a, Kd and PAR) and their relationship support the case 1 water where the fishing activity are done as optical properties of case I water are primary controlled by phytoplankton. The study also motivated to take the remotely sensed data of said variables for understanding their influences on fish catch.

Acknowledgement

The authors are grateful to the Director CIFE, Mumbai, for providing the facilities to carry the work. The authors are also thankful to INCOIS, Hyderabad, India, for permitting to utilize the mentioned *in-situ* data of SST and Chl-a for Gujarat region. This paper forms part of the Ph.D. thesis of the first author. The authors sincerely thank the Director, Indian Institute of Technology Bombay, India, for providing necessary facilities for the study

References

1 Singh, R.P. and Chaturvedi, P., Comparison of Chlorophyll concentration in the Bay of Bengal and the Arabian sea using IRS-P4 OCM and MODIS Aqua, *Indian J. Mar. Sci*., 39:3(2010) 334-340

2 Emery, W. J., Castro, S., Wick, G. A., Schluessel, P. and Donlon, C., Estimating Sea Surface Temperature from

Infrared Satellite and In Situ Temperature Data, *Bulletin of the Americ. Meteorolo. Society*, 82:12(2001), pp.2773-2785

3 Anand, A., Kumari, Beena, Nayak, S.R., Murthy, and Krishna,Y.V.N., Locating oceanic Tuna resources in the eastern Arabian sea using remote sensing, *Journal of Ind. soci. of remote sens*., 33:4(2005), pp.512-520

4 Miroslaw, D. and Stramskib, D., An evaluation of MODIS and SeaWiFS bio-optical algorithms in the Baltic Sea, *Remote sens. of Env.* 89(2004) 326 – 350

5 Chunhuaqiu, W.D., Kawamura, H. and Huilingqin, L., Validation of AVHRR and TMI-derived sea surface temperature in the northern South China Sea‖, *Continental Shelf Res.*, Vol. 29(2009), pp. 2358-2366

6 SeaDAS, The official NASA processing software, http://seadas.gsfc.nasa.gov/2017

7 Brown, O.B., Minnett, P.J., Evans, R., Kearns, E., Kilpatrick, K., Kumar, A., Sikorski, R., and Závody, A., *MODIS Infrared Sea Surface Temperature Algorithm, Algorithm Theoretical Basis Document Version* 2.0(1999),(University of Miami)

8 Franz, B., SAIC, *Programing Code for computing the long wave Sea Surface Temperature for MODIS/ Aqua senso,* August 2003. Retrieved from the below link on 22nd August 2014 http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/CODE/sst.c

9 Minnett, P.J., Evans, R.H., Kearns, E.J. and Brown, O.B., Sea-surface temperature measured by the Moderate Resolution Imaging Spectroradiometer (MODIS), *Geoscience and Remote Sensing Symposium*, 2002, IGARSS '02. IEEE International Volume: 2, pp. 1177-1179

10 Diffuse attenuation coefficient for downwelling irradiance at 490 nm (Kd_490), http://oceancolor.gsfc.nasa.gov/atbd/kd_490/(2017)

11 Photosynthetically Active Radiation (PAR), http://oceancolor.gsfc.nasa.gov/atbd/par/(2017)

12 Frouin, R., Franz, B. A., and Werdell, P. J., *The SeaWiFS PAR product. ,In S.B. Hooker and E.R. Firestone, Algorithm Updates for the Fourth SeaWiFS Data Reprocessing*, NASA Tech. Memo. 2003-206892, Volume 22(2002), NASA Goddard Space Flight Center, Greenbelt, Maryland, 46-50.

13 Nurdin, S., Mustapha, M.A., and Lihan, T., The relationship between sea surface temperature and chlorophyll-a concentration in fisheries aggregation area in the archipelagic waters of spermonde using satellite images, *AIP Conference Proceedings,* 1571(2013), pp. 466-472.

14 Madhavan, N., Thirumalai, V. D., Ajith, J. K. and Sravani, K., Prediction of Mackerel Landings Using MODIS Chlorophyll-a, Pathfinder SST, and SeaWiFS PAR, *Indian J. Of Nat. Sci*.,5:29(2015), pp.4858-4871

15 Morel, A., Huot, Y., Gentili, B., Werdell, P. J, Hooker, S. B. and Franz, B. A. (2007). Examining the consistency of products derived from various ocean color sensors in open ocean (Case 1) waters in the perspective of a multi-sensor approach, *Remote Sen. of Env*., 111(2007) 69–88