EVALUATION OF MODIS OCEAN COLOR PRODUCTS FOR COASTAL APPLICATIONS: A CASE STUDY IN LIAN, BATANGAS

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ABSTRACT: Field validation activities are important in the assessment and evaluation of satellite data. A field validation from March 15 to 17, 2016 was done in the coastal waters of Lian, Batangas, located in the north western part of the country. The activity includes a total of 27 sampling points where radiance values and chlorophyll-a concentration from filtration and fluorometry were measured. The chlorophyll-a concentration distribution of the samples ranges in the mesotrophic levels, particularly from 0.1 to 0.37 mg/m^3. In situ chlorophyll-a concentration varies linearly with Aqua MODIS level 2 chlorophyll-a product, with a coefficient of determination of 0.2421. Maximum band ratio (MBR) values for Aqua MODIS level 2 remote sensing reflectance (Rrs) were further compared with the MBR of ground-measured Rrs. The bands considered in the maximum band ratio are centered at 443, 489 and 547 nm based on the OCI algorithm used by MODIS. The two variables have a linear relationship with an R^2 of 0.5635. The atmospheric correction applied in converting L1 to L2 products highly accounts for the significant difference between the Rrs values, and subsequently in the chlorophyll-a concentration of the satellite data and the in situ measurements.

1. INTRODUCTION

The Philippine archipelago has a coastline that extends up to approximately 36,000 km which is considered as one of the longest in the world. Located in these areas are coastal resources that include a rich biodiversity of marine fisheries and ecosystems such as coral reefs, mangroves and seagrasses. These resources contribute significantly to the country's food security, economic development, and shoreline protection for the coastal communities that are made up of more than half of the country's population. According to the Bureau of Fisheries and Aquatic Resources (BFAR), the Philippine municipal fisheries and aquaculture in the inland and coastal waters account for 26.5% and 49.9% of the total fish production in 2014.

In line with the country's growing population, the coastal resources are vulnerable to overexploitation. Moreover, coastal areas are also prone to natural disasters, pollution and sedimentation (White and Trinidad, 1998). Mitigation measures, therefore, are necessary. The local government units have the responsibility of monitoring the coastal resources to promote sustainability for the growing population (DENR, BFAR and DILG 2001; TWBG, 2003). Proper management of the resources and ecosystems requires the need of spatial and temporal information of environmental indicators. Through this, remote sensing and modeling is linked with resource monitoring and management (Phinn et al., 2000).

Remote sensing, Geographic Information Systems (GIS), and modeling can be utilized in various applications such as coral reefs change detection, marine protected areas (MPA) monitoring, mangrove coastal retreat monitoring, wetlands monitoring, coastal change detection, and species distribution modeling. Archives of reliable remotely-sensed data are necessary for such studies.

The National Aeronautics and Space Administration Ocean Biology Processing Group (NASA OBPG) provides a vast archive of both raw and pre-processed ocean-related satellite data. This includes Aqua MODIS' chlorophyll-a (chl-a) and sea surface temperature (SST) datasets which are both considered as main parameters in various studies. In the Philippines, these datasets can be used to assess the distribution of marine species particularly fish and to monitor important ecosystems such as coral reefs and mangrove forests. In line with this, ground truthing is necessary to assess the validity of remotely-sensed data for higher level applications (Pe'eri, 2013). NASA's SeaWiFS Bio-Optical Archive and Storage (SeaBASS), on the other hand, serves as a local repository of field validation datasets but unfortunately there are not enough measurements in the Philippine area. Thus, there is a need to conduct validation activities at a local scale. This study aims to compare the satellite-derived chl-a and

SST datasets with in-situ measurements in the coastal waters of Lian, Batangas, located 127 km south of Metro Manila. The town of Lian primarily supports fishing communities and several tourist attractions. This is the first of several validation activities to be performed from 2016-2018.

In addition, DIWATA-1, the first microsatellite built and developed by Filipino scientist and engineers together with professors from Hokkaido and Tohoku universities, has a Spaceborne Multispectral Imager (SMI) payload. The spectral range of this payload can be adjusted to collect bands necessary for ocean color remote sensing applications. This study also aims to initiate a database for the calibration of DIWATA-1's possible ocean products.

2. METHODOLOGY

2.1 Site selection

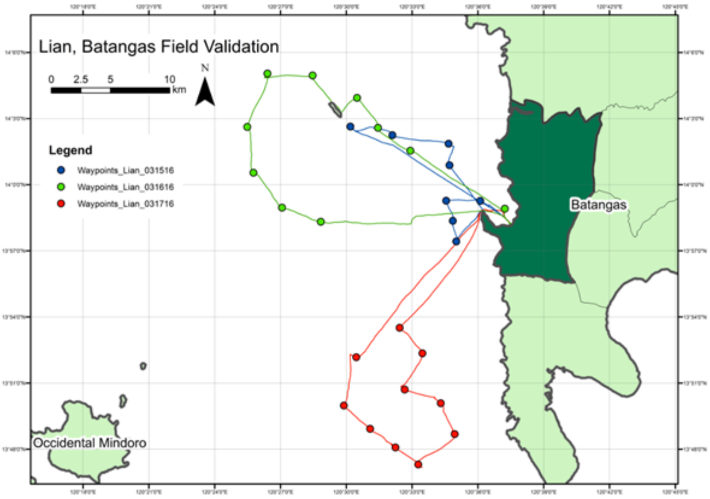

Figure 1. The site map and sampling stations in Lian, Batangas

Stratified random sampling was implemented in the site selection to achieve a good representation of chl-a and SST values. Also, this sampling method was utilized to maximize the available resources. Using the satellite imagery from a maximum of three days prior to the sampling date, random points from stratified areas with varied chl-a concentration were selected as measurement sites. Figure 1 shows a map of the field area as well as the sites where various parameters were measured. The blue, green, and red dots represent the sampling sites for each day. For three days, there were a total of 27 sample sites were validated. In each site, chl-a filtration, CTD deployment and spectroscopic measurements were done. The field validation was conducted from March 15 to 17, 2016.

2.2 Field measurements

To measure chl-a, seawater samples were collected in Nalgene bottles and chl-a was filtered on-site using a Merck Millipore filtration setup with a 0.45µm pore size filter. Three samples were collected and filtered in each sampling site. The filter papers containing the filtered samples were stored in vials and frozen until it is ready for extraction in the laboratory. Chl-a was extracted from the frozen filter paper by transferring it to a test tube containing acetone. Samples were sonicated and centrifuged to separate the chl-a from the filter paper. The chl-a concentrations of each samples were measured using a table-top Turner Trilogy laboratory fluorometer.

Conductivity, Temperature and Depth (CTD) were measured during the field campaign using the SBE 19Plus V2 CTD instrument. The depth at which the CTD was submerged is based on the bathymetry data from the General Bathymetric Chart of the Oceans (GEBCO). The datasets collected were post-processed by using the wild edit, align CTD and cell thermal mass module functions of SBE data processing software to obtain temperature at varying depths. Data averaging was done using Matlab 2015a.

2.3 Spectroscopy and Satellite Datasets

The upwelling radiance (L_{u-}) and downwelling irradiance (E_{d-}) below the water surface was measured using ASD Field Spec 4 hyperspectral radiometer equipped with underwater accessories to derive in-situ remote sensing reflectance. The remote sensing ratio (rrs) was calculated using equation 1. The remote sensing ratio was converted to remote sensing reflectance (Rrs) using the relation given by equation 2 (Cannizzaro and Carder, 2005).

$$\mathrm{rrs} = \frac{\mathrm{Lu-}}{\mathrm{Ed-}} \quad (1)$$

$$\mathrm{Rrs} = \frac{0.5 * \mathrm{rrs}}{1 - 1.5 * \mathrm{rrs}} \quad (2)$$

Daily Level 2 chl-a, SST, and Rrs products were downloaded and viewed using SeaDAS 7.0. The equation used for deriving the chl-a values is shown in equation 3 (NASA OBPG). Based on the OCI algorithm used by MODIS, corresponding Rrs in 443, 488 and 547 nm were used to determine the maximum band ratio (MBR). The MBR is useful since it is the basis of most satellite-derived chl-a measurements. The chlor_a and sst subset products were exported as GeoTIFF and transferred to Arcmap 10.2.2. The values were extracted to Global Positioning System (GPS) points using the spatial analyst tool. For sites with no available data on the exact date, readings from the nearest date were used.

$$log_{10}\,(chl - a) = a_0 + \textstyle\sum_{i=1}^{4} a_i \, log_{10}\,(MBR)^i \quad (3)$$

$$\text{where } MBR = \frac{\max(R_{rs}(443_{Rrs}, 488_{Rrs})}{R_{rs}(\lambda_{green})}$$

3. RESULTS AND DISCUSSION

3.1 Chl-a distribution

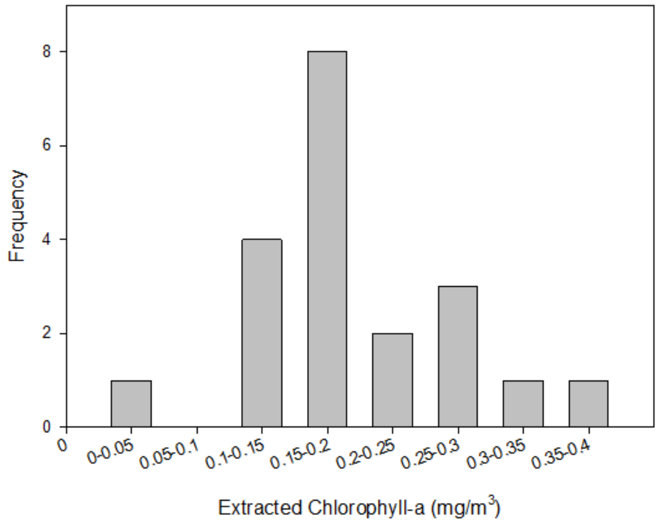

Figure 2. Frequency distribution of chl-a concentrations measured in-situ

Chlorophyll concentration in the ocean can provide an approximation of the phytoplankton biomass present in the surface. Figure 2 shows the distribution of chl-a concentrations collected from the field. It can be observed that the measured chl-a concentrations have values up to 0.4 mg/m^3. The highest frequency occurs in the concentration range of 0.15-0.2 mg/m^3. Chl-a values between 0.1-1 mg/m^3 indicate mesotrophic waters. The collected chl-a concentrations for the study area fall under the mesotrophic water range which may indicate moderate levels of productivity. As seen in the site map (Fig. 1), 27 sampling sites were used in this study.

3.2 In-situ and satellite chl-a

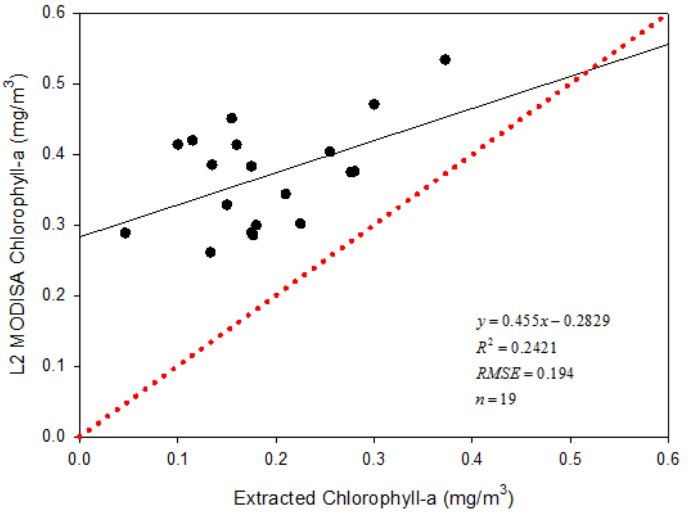

Figure 3. Concentrations of MODIS L2 chl-a and chll-a measured in the field

Figure 3 shows the relationship between level 2 (L2) MODISA chl-a product and chl-a concentrations measured in the field. It can be observed that L2 MODISA chl-a values are higher compared to in-situ chl-a concentrations. Linear regression between the two parameters show a positive but low correlation with R^2 of 0.24. The calculated RMSE is 0.19 which is high relative to the chl-a values. The poor correlation is indicative of the inhomogeneous chl-a distribution within the 1km resolution of MODIS. The overestimated chl-a values of MODIS can also be attributed to calibration errors and atmospheric correction. The atmospheric correction used in converting L1 to L2 products highly accounts for the significant difference in the chl-a concentration of the satellite data and the in-situ measurements since it affects the value of computed Rrs.

3.3. In-situ and satellite SST

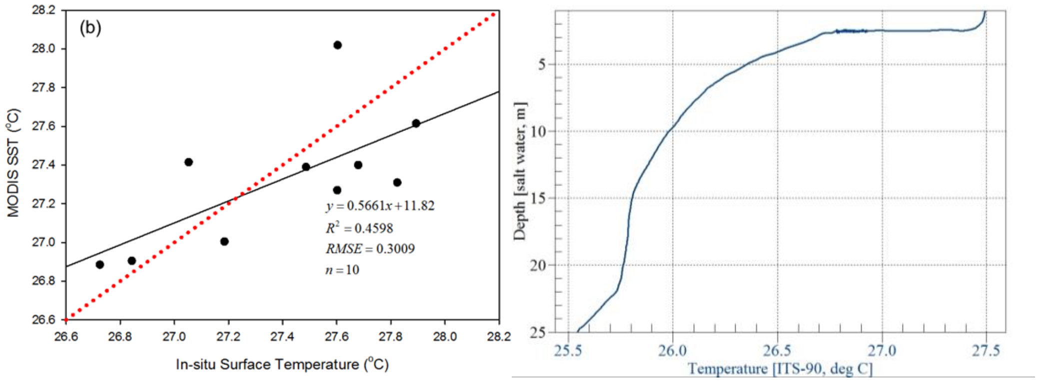

Figure 4. a) Temperature profile in site taken on 13 March 2016 and (b) correlation of in-situ measurement (CTD) with satellite (MODIS) SST.

Sea surface temperature is among the most important parameters in ocean studies. SST measurements for both the MODIS and the CTD instrument were between 26.7- 28.0ºC as observed in Figure 4a. Linear regression showed a correlation value of 0.46 and low RMSE of 0.30ºC. The low RMSE of SST values reflects the minimal variability of MODIS temperature within the 1km resolution as compared to the chl-a data. Deviations of the MODIS SST from the ground-measured data can be attributed to the delay in the measurement time between the satellite and ground instrument. It can be further observed that the mixed layer depth shown in Figure 4.b where the temperature is nearly constant at certain depths is very narrow, resulting to a shallower thermocline. This is because of the generally calm waters during the field validation. This might also attribute for the low correlation between the satellite and in situ chl-a because the phytoplankton concentration are affected by temperature.

3.4. In-situ and satellite maximum band ratio (MBR)

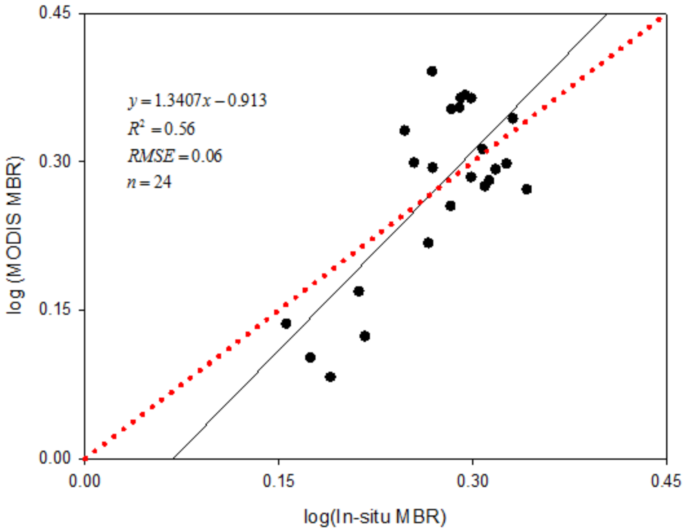

Figure 6. Correlation between MODIS and ground-measured MBR

Most satellite-derived measurements of chl-a are based on blue-green band ratios (e.g. MODIS, Landsat 8, SeaWiFs). This is apparent in equation 3 where the MODIS algorithm for chl-a utilizes the logarithm of the maximum band ratio (MBR). Furthermore, the MBR was analyzed in lieu of the corresponding Rrs in 443, 488 and 547 nm since this parameter unlike the Rrs is less variable with the sun and sensor geometry/conditions which may result to additional errors due to differing time acquisitions of the satellite and ground measurement. The MBR calculated from MODIS was correlated to ground-measured MBR to partially assess the accuracy of satellite-derived ocean parameters. This is shown in Figure 6. A strong linear correlation with an R^2 of 0.56 was observed between MODIS and ground-measured MBR The calculated RMSE of 0.06 can still be improved by i) having additional validation sites with MBR ranging from -0.5 to 1 and ii) more appropriate atmospheric correction of satellite-derived optical reflectance.

4. CONCLUSION

In this study various MODIS ocean color products namely chl-a, SST and MBR, were correlated with field measurements collected in Lian, Batangas. The assessment of the MODIS data accuracy in predicting ocean color parameters is essential since it can provide information regarding the possible applications of the product. Ground measurements of chl-a concentrations in the study area indicate mesotrophic waters. Ground-measured chl-a concentrations showed a linear correlation with Aqua MODIS level 2 chl-a product. MBR values derived from MODIS Rrs and in-situ radiance measurements also have a linear relationship. Deviations between the MODIS ocean color products and the field measurements can be attributed to calibration errors of the satellite sensor. The atmospheric correction used in converting L1 to L2 MODIS products can also account for the significant difference between the Rrs values which in turn affects the correlation of derived chl-a concentration of the satellite data and the in situ measurements. It is recommended that the atmospheric correction model used in the derivation of the MODIS products be further improved particularly for coastal waters. It is also highly recommended that the validation results be integrated in developing more consistent satellite products for coastal areas. The initial results presented in this paper will also serve as preliminary data that can contribute to the development of the ocean color products of DIWATA-1, the Philippines' first earth-observation microsatellite.

5. ACKNOWLEDGEMENT

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